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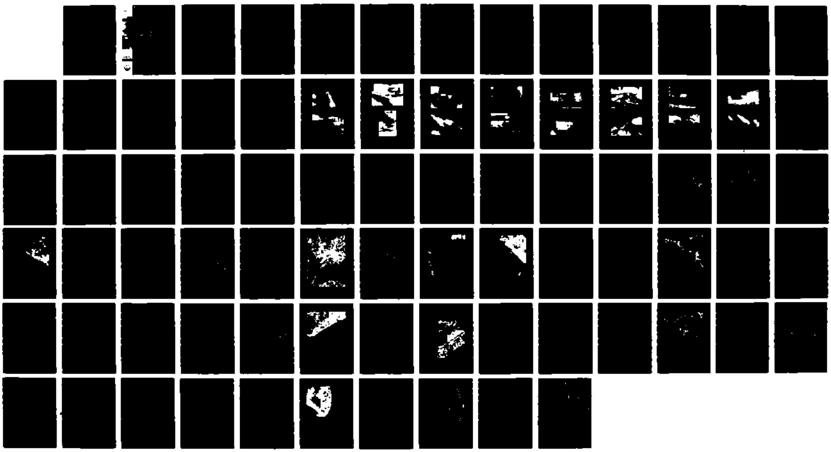

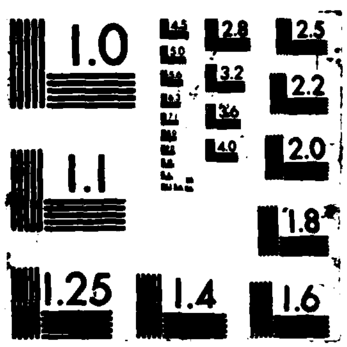
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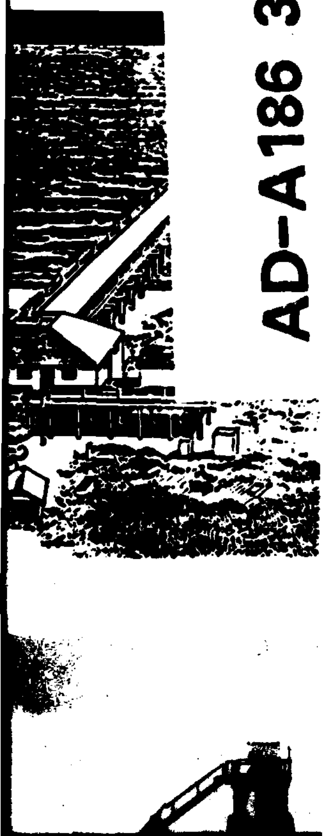

TECHNICAL REPORT CERC-87-12

HURRICANE KATE STORM SURGE DATA

Report 5

by

Andrew W. Garcia, William S. Hegge

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

August 1987

Report 5 of a Series

Approved For Public Release, Distribution Unlimited

Prepared for DEPARTMENT OF THE ARMY
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Washington, DC 20314-1000

Under Hurricane Surge Prototype Data Collection
Work Unit 321-31662

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A summary of storm surge high-water mark, hydrograph, and wave data acquired during and subsequent to Hurricane Kate is presented. The data were obtained and assembled as part of a long-term research effort by the US Army Corps of Engineers to establish a quantitative data set with the objective of providing, in a series of documents, the data necessary for simulation and verification of numerical surge models. The data contained herein were obtained primarily by the US Army Engineer Waterways Experiment Station and the US Army Engineer District, Mobile, with supplemental data from contributing agencies and institutions. Additional information is included in the form of photographs and a descriptive narrative to aid investigators in assessing the degree of importance of an individual measurement for the purpose of model verification.

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Hurricane Surge Prototype Data Collection Work Unit 321-31662

PREFACE

The information and data presented herein were assembled and analyzed during 1985 to 1986 by authorization from the Office, Chief of Engineers (OCE), Coastal Engineering Area of Civil Works Research and Development, as a mission requirement of the Hurricane Surge Prototype Data Collection Work Unit 321-31662. Messrs. John H. Lockhart, Jr., and John Housley are the OCE Technical Monitors for the Coastal Engineering Research Area.

The work unit is a multiyear project of the Coastal Engineering Research Center (CERC), US Army Engineer Waterways Experiment Station (WES), under general supervision of Dr. James R. Houston, Chief, CERC; Mr. Thomas W. Richardson, Chief, Engineering Development Division; and Dr. Dennis R. Smith, former Chief, Prototype Measurement and Analysis Branch (CD-P). Dr. Charles L. Vincent is CERC Program Manager. Mr. Andrew W. Garcia, CD-P, is the Principal Investigator of the Hurricane Surge Prototype Data Collection work unit, and Mr. William S. Hegge, CD-P, is the engineer in charge of data collection activities. This report was prepared by Messrs. Garcia and Hegge and edited by Ms. Jamie W. Leach, Information Products Division, Information Technology Laboratory, WES.

A special acknowledgment is due Messrs. Geary McDonald and Harold Doyal of the US Army Engineer District, Mobile, for their cooperation in acquiring and assembling the high-water mark data and for providing interpretive guidance thereon.

This report is fifth in a series. Reports 1-4 provided similar data on Hurricanes Chris, Alicia, Elena, and Danny, respectively.

Commander and Director of WES during report publication was COL Dwayne G. Lee, CE. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
knots (international)	0.5144444	metres per second
miles (US statute)	1.609347	kilometres
millibars	100.0000	pascals

HURRICANE KATE STORM SURGE DATA

PART I: INTRODUCTION

1. This report is the fifth in a series* providing a data base directed toward verification of numerical storm surge models. As such, the emphasis is on quantitative measurements of the hydrodynamic and meteorologic parameters of Hurricane Kate rather than documentation of structural damage or changes in coastal morphology. Photos 1-16 show areas which experienced significant surge effects and are included to assist investigators in assessing the applicability of individual high-water marks in verifying a particular numerical model.

2. Contained herein are coastal and inland hydrographs and basic meteorological data associated with Hurricane Kate. These data have been compiled from a variety of sources; consequently, they cannot be guaranteed to be absolutely accurate. Nevertheless, every reasonable effort has been made to ensure the data are as consistent and complete as possible.

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* Thomas H. Flor. 1983 (Jul). "Poststorm Reconnaissance of Tropical Storm Chris," Miscellaneous Paper HL-83-5, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.
Andrew W. Garcia and Thomas H. Flor. 1984 (Nov). "Hurricane Alicia Storm Surge and Wave Data," Technical Report CERC-84-6, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.
Andrew W. Garcia and William S. Hegge. 1987. "Hurricane Elena Storm Surge Data," Technical Report CERC-87-10, Report 3, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.
Andrew W. Garcia and William S. Hegge. 1987. "Hurricane Danny Storm Surge Data," Technical Report CERC-87-11, Report 4, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

PART II: METEOROLOGICAL DISCUSSION

3. Hurricane Kate was first identified as a weak tropical wave located northeast of the Virgin Islands on 13 and 14 November 1985.* The system strengthened rapidly and already had attained tropical storm intensity when first investigated by reconnaissance aircraft on 15 November 1985. Atmospheric conditions in the area favored further development, and Kate reached hurricane intensity by the afternoon of 16 November while located just north of the Virgin Islands. During the next 48 hr, Kate moved on a track just north of due west and continued to intensify. By late afternoon on 19 November, the eye of Kate had moved onshore the north-central coast of Cuba. The eye of Kate remained overland during the next 12 hr emerging just east of Havana at about 0000 hr Greenwich mean time (Gmt). During the passage over Cuba, the central pressure of Kate had risen from 967 to 976 mb.**

4. After crossing Cuba, the eye of Kate passed within about 90 miles of Key West. Maximum sustained winds recorded at Key West were about 47 mph. Coincident with entering the Gulf of Mexico, Kate intensified very rapidly during the following 24 hr with the central pressure dropping nearly 1 mb per hour from 972 mb, reaching the lowest recorded pressure of 953 mb at 2000 Gmt on 20 November. During this period, the center of Kate passed very close to the National Oceanic and Atmospheric Administration data buoy located near latitude 26.0 deg N, longitude, 85.9 deg W which reported a peak wind gust of 135 mph.

5. Shortly after entering the Gulf of Mexico, Kate began to turn toward the north where it encountered the late season, cooler surface waters of the Gulf which, combined with unfavorable atmospheric conditions, caused Kate to weaken as it passed latitude 27° N. Upon landfall near Mexico Beach, Fla., early on the evening of 21 November, the central pressure of Kate had risen to 967 mb, and maximum winds had decreased from 121 to 98 mph. Kate moved inland in the vicinity of Tallahassee, Fla., and was downgraded to a tropical storm

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* The meteorological discussion and information contained in Table 1 are taken from the preliminary report on Hurricane Kate provided by the National Hurricane Center.

** A table of factors for converting non-SI units of measurement to metric (SI) units is presented on page 3.

Table 1

Preliminary Best Track - Hurricane Kate

15-23 November 1985

Date	Time Gmt	Position, deg Latitude	Position, deg Longitude	Pressure mb	Wind knots	Stage
11/15	1800	21.1	63.0	999	35	Tropical storm
11/16	0000	21.6	63.9	998	45	Tropical storm
11/16	0600	21.7	64.2	996	50	Tropical storm
11/16	1200	21.5	64.8	993	55	Tropical storm
11/16	1800	21.1	65.3	987	70	Hurricane
11/17	0000	20.7	66.0	981	75	
11/17	0600	20.4	66.4	984	75	
11/17	1200	20.7	67.3	982	75	
11/17	1800	21.1	68.8	977	80	
11/18	0000	21.4	70.8	976	80	
11/18	0600	21.6	71.8	975	80	
11/18	1200	21.6	73.3	975	80	
11/18	1800	21.9	75.1	972	85	
11/19	0000	22.1	76.0	967	95	
11/19	0600	22.1	78.4	968	95	
11/19	1200	22.7	80.2	971	90	
11/19	1800	23.2	81.9	976	80	
11/20	0000	23.9	83.5	972	85	
11/20	0600	24.6	84.5	968	95	
11/20	1200	25.2	85.3	956	105	
11/20	1800	26.0	86.0	955	105	
11/21	0000	26.8	86.5	954	105	
11/21	0600	27.5	86.6	961	100	
11/21	1200	28.3	86.5	965	95	
11/21	1800	29.2	86.1	967	85	
11/22	0000	30.2	85.1	975	80	
11/22	0600	31.5	83.5	983	65	
11/22	1200	32.5	81.5	990	50	Tropical storm
11/22	1800	33.7	79.2	996	45	
11/23	0000	34.7	76.2	1003	40	Tropical storm
11/23	0600	34.4	73.5	1005	35	Tropical storm
11/23	1200	34.0	72.0	1006	35	Tropical storm
11/23	1800	33.5	70.5	1006	35	Extratropical
			Minimum Pressure			
11/20	2000	26.2	86.2	953	105	Hurricane
			Landfall			
11/21	2230	30.0	85.4	967	85	Hurricane

by early morning on 22 November. Figure 1 shows the approximate track of Kate. Table 1 contains the preliminary best-track information.

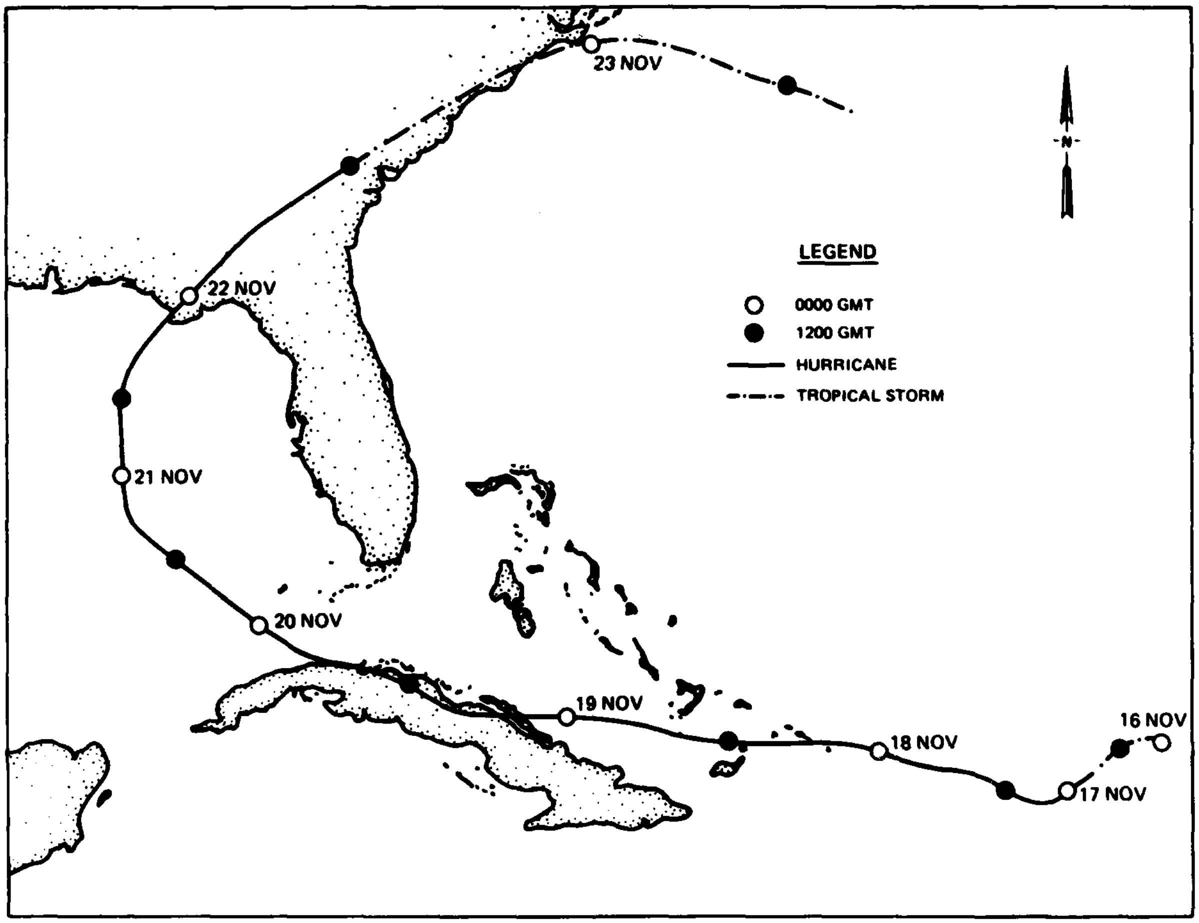

Figure 1. Approximate track of Hurricane Kate

PART III: FIELD ACTIVITIES

6. Prior to 20 November, it was uncertain if Kate would move northward along the east or west coast of Florida. After emerging from the northwest coast of Cuba, Kate appeared very likely to make landfall somewhere along the Gulf of Mexico coastline. The Coastal Engineering Research Center (CERC) field teams had been placed on alert status on 19 November. On 20 November a hurricane warning was issued from Bay St. Louis, Miss., to St. Marks, Fla., and the field teams began to deploy the onshore gages. At this time Kate was expected to make landfall sometime on 22 November. The first field team installed instrumentation in the reach of coastline from Pass Christian, Miss., to Pensacola, Fla. The second team deployed gages from Fort Walton Beach to Panama City, Fla.

7. During the night of 20 November, the forward speed of the hurricane slowed to almost 5 mph while maintaining a northerly course. On the morning of 21 November, Kate was located about 145 miles due south of Fort Walton Beach. By the morning of 21 November, instrument packages had been deployed along the coastline from Pass Christian, Miss., to Panama City, Fla. At about noon on 21 November, a hurricane warning was issued for the area from Pensacola, Fla., to St. Marks, Fla. At this time, the center of Kate was located about 95 miles south-southwest of Panama City moving toward the north-northeast at about 12 mph. During the remainder of the afternoon, Kate continued to turn eastward and made landfall near Mexico Beach, Fla., during the early evening hours on 21 November.

8. Following the passage of Kate, the CERC field team returned to the area of landfall and conducted a poststorm survey. Highlights of the survey are contained in Part V.

PART IV: HYDROGRAPHIC DATA

9. Figures 2 and 3 show the locations of hydrographs covering the reach of coastline from Pensacola, Fla., to Cedar Key, Fla., the area significantly affected by Kate. The hydrographs are contained in Plates 1-10. The hydrographs obtained at Pensacola, Destin, and Panama City (Plates 1, 2, and 3, respectively) show a gradual rise and fall of water levels characteristic of the left side of a landfalling hurricane. With the exception of the hydrograph obtained at Cedar Key, the remaining hydrographs show the sudden rise and fall of water levels characteristic of the right side of a landfalling hurricane. Table 2 contains a listing of the maximum gage elevations recorded during Kate.

10. Preliminary surge estimates as large as 12 ft in the vicinity of Cape San Blas, Fla., were reported shortly after Kate made landfall. However, these estimates included the effects of wave runup. The hydrograph obtained at Apalachicola, approximately 24 miles east of Cape San Blas and 30 miles southeast of Mexico Beach, recorded a maximum elevation of 7.2 ft NGVD. The highest recorded gage level was 7.9 ft MSL (approximately 8.8 ft NGVD) at Shell Point, Fla. (Plate 8), near Oyster Bay. This value is in excellent agreement with a reliable high-water mark of 8.3 ft NGVD obtained nearby.

11. The peak of the surge at Apalachicola coincided with predicted low tide. However, since the predicted tide range on 21 November was only 0.9 ft (see Plate 5), the contribution of the tide to the surge at this location was not particularly significant. At Turkey Point and Shell Point, the surge peak coincided with predicted mean tide level (see Plates 7 and 8); consequently, the peak surge value can be considered to be a good estimate of the hurricane-generated surge with little tide or wave effects. The hydrograph obtained at Cedar Key indicates an increase in local water level which corresponds to the approximate time Kate entered the Gulf of Mexico and continues until shortly after landfall. During the period from approximately noon on 20 November to noon on 22 November, measured water levels at Cedar Key were about 2 ft higher than predicted.

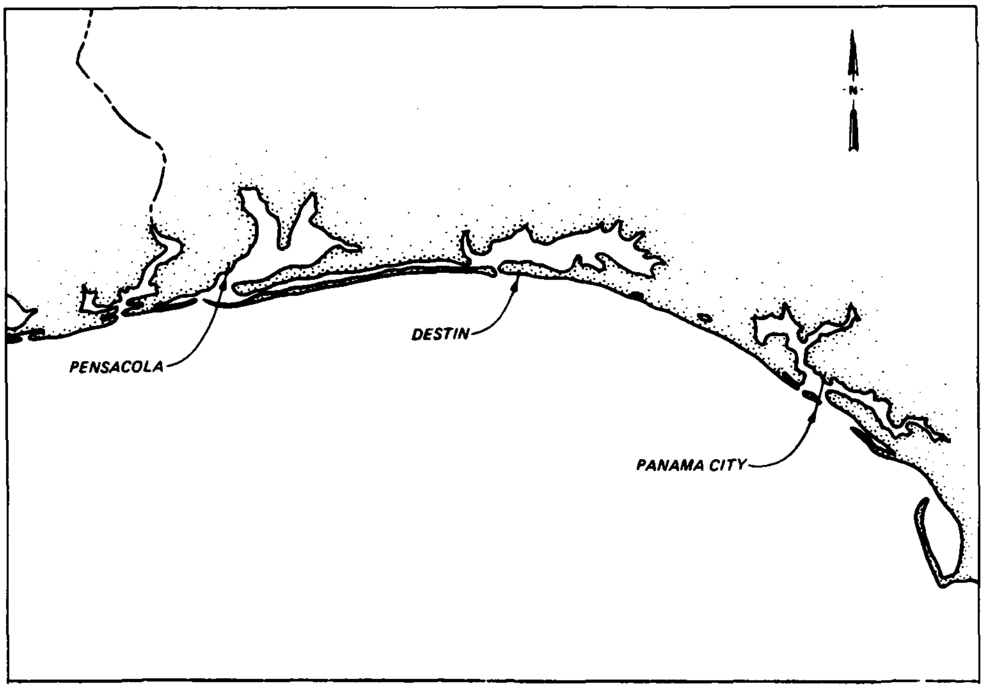

Figure 2. Locations where hydrographs were obtained as shown in Plates 1-3

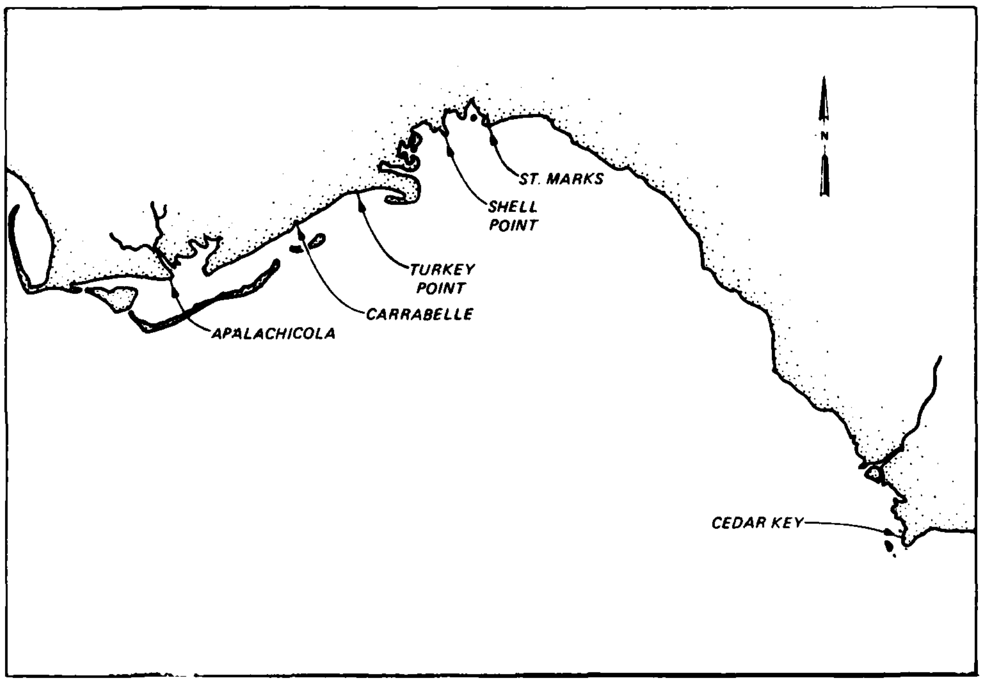

Figure 3. Locations where hydrographs were obtained as shown in Plates 4-10

Table 2

Times and Heights of Maximum Elevations

Location	Maximum Water Level, ft	Time, CST/Date	Datum	Source
Pensacola, Fla.	2.0	1300/21/11/85	MSL	NOS
Destin, Fla.	2.5	1600/21/11/85	NGVD	CE
Panama City, Fla.	3.5	1630/21/11/85	MSL	NOS
Apalachicola, Fla. (Site 1)	7.2	1700/21/11/85	NGVD	CE
Apalachicola, Fla. (Site 2)	6.4	1800/21/11/85	MSL	NOS
Carrabelle, Fla.	7.4	1800/21/11/85	NGVD	CE
Turkey Point, Fla.	7.3	1900/21/11/85	MSL	NOS
Shell Point, Fla.	7.9	2000/21/11/85	MSL	NOS
St. Marks, Fla.*	6.5	2200/21/11/85	NGVD	NOS
Ceder Key, Fla.	3.3	2200/21/11/85	MSL	NOS

Note: CST = Central Standard Time.
MSL = Mean sea level.
NOS = National Ocean Service.
NGVD = National Geodetic Vertical Datum.
CE = Corps of Engineers.
* Incomplete record.

PART V: POSTSTORM SURVEY

12. A poststorm survey of the high-water marks due to Hurricane Kate was conducted during the period 22-27 November 1985. The survey included the reach of coastline from Gulf Shores, Ala., to St. Marks, Fla. The elevations of high-water marks did not exceed +9 ft, but at some locations combined surge and wave runup exceeded 16 ft.

13. There was minor wind damage throughout the western end of the Florida panhandle. The westernmost location where significant damage was observed was Panama City Beach, Fla. The major beach erosion that occurred throughout the eastern part of the panhandle began here. The extent of erosion is evident in the condition of the seawall just west of the Rendezvous Motel in Panama City Beach (Photo 1). The elevation of the surge-induced flooding was approximately 5 ft.

14. At Mexico Beach, the erosion was more severe, uncovering and destroying a seawall (Photo 2) that had been completely buried by a sand dune prior to the hurricane. Surge elevations estimated at this location from the watermark on the side of the canal on the west end of town (Photo 3) were approximately 7 ft. Wind damage in this area was relatively minor.

15. The extent of wind damage increased rapidly farther east; an example can be seen by the stripped siding and insulation on a storage tank at the paper company in Port St. Joe (Photo 4). However, the amount of surge damage in Port St. Joe was minimal due to the excellent protection offered by the St. Joseph spit offshore. The spit itself suffered massive erosion, as can be seen by the scarp cut into the duneline at the St. Joseph Peninsula State Park (Photo 5). The combined surge and wave runup at this location exceeded +16 ft.

16. Property damage within the park was confined to boardwalks (Photo 6) due to the lack of construction along the beachfront. Farther south at Cape San Blas, there was more extensive damage. Several homes were totally destroyed (Photo 7), and houses that survived were undermined by beach erosion (Photo 8). The surge elevation at this location was approximately at 9 ft. Many of the buildings located far enough from the beach to be protected from surge damage suffered wind damage (Photo 9).

17. An attempt was made to survey St. George Island; however, surge-induced flooding had undermined the approach ramp at the mainland end of the

bridge to the island, cutting off all vehicular access (Photo 10). Damage was significant on the protected mainland coast behind the island. Several miles of Highway 98 along the coast between Cape San Blas and Carrabelle were undermined and had collapsed (Photos 11 and 12). The Hut Restaurant in Apalachicola was completely destroyed (Photo 13). Between East Point and Carrabelle, several homes and trailers located on waterfront lots were totally destroyed (Photos 14 and 15). Farther east, at Lighthouse Point, there was more destruction (Photo 16). Throughout this area, surge elevations were approximately 7 ft. Wind and surge damage, although less severe, was reported as far east as Ceder Key, Fla.

PART VI: CONCLUSION

18. Hurricane Kate was only the fourth November hurricane to landfall in the United States this century and the first since the 30 October - 5 November hurricane of 1935. During transit through the Gulf of Mexico, Kate attained Category 3 on the Saffir-Simpson scale which ranges from 1 (least intense) to 5 (most intense). The surface waters of the Gulf of Mexico, which had undergone seasonal cooling prior to Kate's transit, caused the hurricane to weaken during the 24 hr before making landfall near Mexico Beach, Fla. At its peak Kate was a medium-sized hurricane with winds in excess of 55 mph extending over 100 miles in the east and north quadrants and gale force winds extending 100 miles in the west and south quadrants.

19. Finally, the area of landfall had experienced hurricane effects only 2 months earlier during Hurricane Elena. In some instances, the evaluation of high-water marks was hampered because of the difficulty in determining if marks had predated Kate. Moreover, along some beach areas, damage due to Elena was severe enough that morphological changes due to Kate were indiscernible or absent. For these reasons, gage data were sometimes extrapolated to greater distances than otherwise would have been necessary.

20. A series of contour maps showing the high-water marks from Panama City Beach to St. Marks, Florida, is presented in Appendix A.

Photo 1. Erosion around end of seawall, Panama City Beach, Fla.

Photo 2. Destroyed seawall, Mexico Beach, Fla.

Photo 3. High-water mark, Mexico Beach, Fla.

Photo 4. Damaged tank covering, Port St. Joe, Fla.

Photo 5. Beach erosion, St. Joseph Peninsula State Park, Fla.

Photo 6. Damaged boardwalk, St. Joseph Peninsula State Park, Fla.

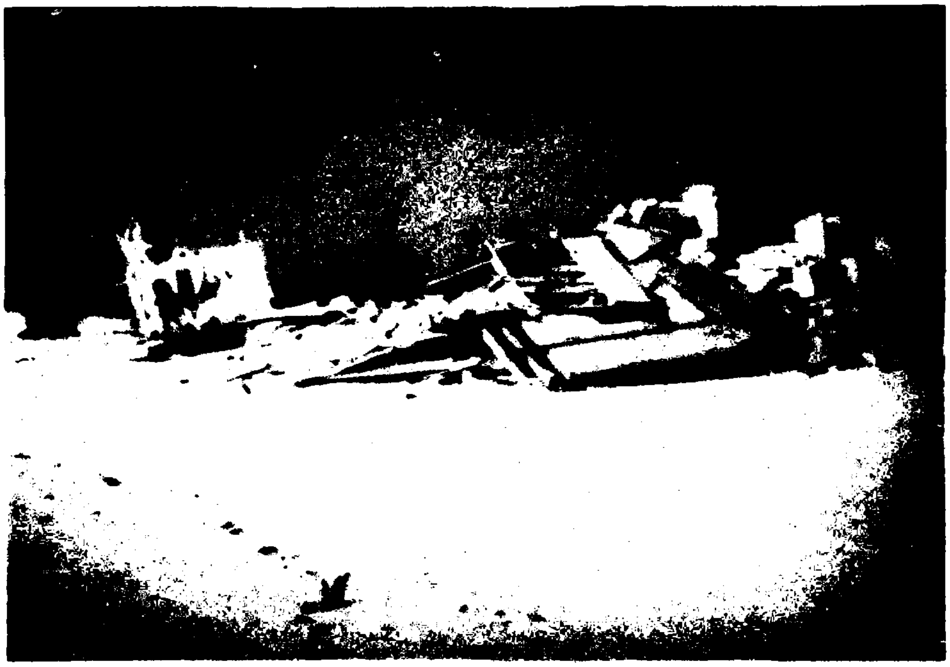

Photo 7. Destroyed house, Cape San Blas, Fla.

Photo 8. Beach erosion under house, Cape San Blas, Fla.

Photo 9. Roof damage, Cape San Blas, Fla.

Photo 10. Highway damage, St. George Island Bridge, Fla.

Photo 11. Highway damage between Cape San Blas and Carrabelle, Fla.

Photo 12. Highway damage near Carrabelle, Fla.

Photo 13. Building destruction, Apalachicola, Fla.

Photo 14. Trailer destruction between East Point and Carrabelle, Fla.

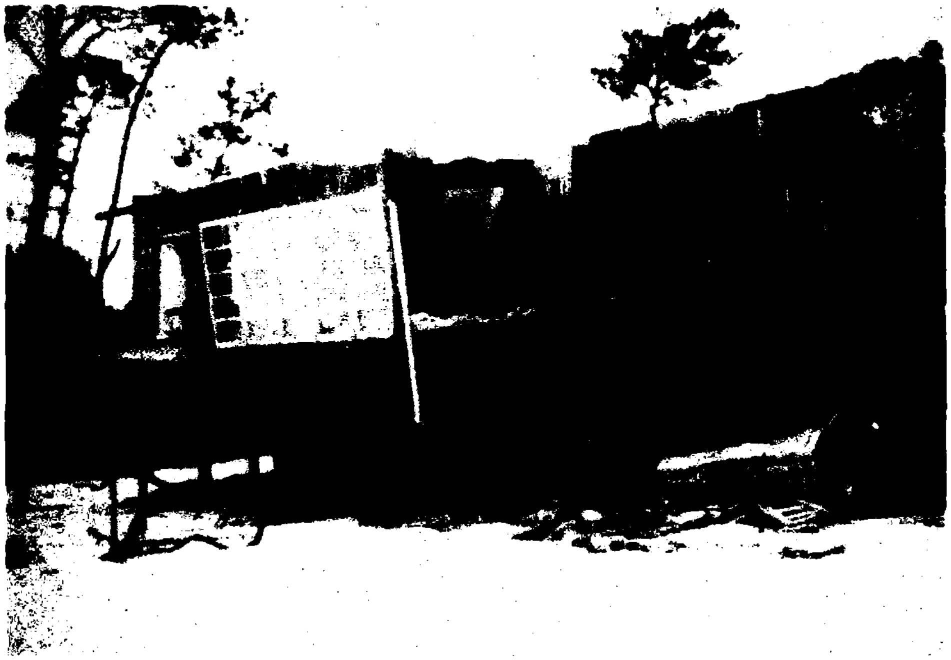

Photo 15. House destruction between East Point and Carrabelle, Fla.

Photo 16. House destruction, Lighthouse Point, Fla.

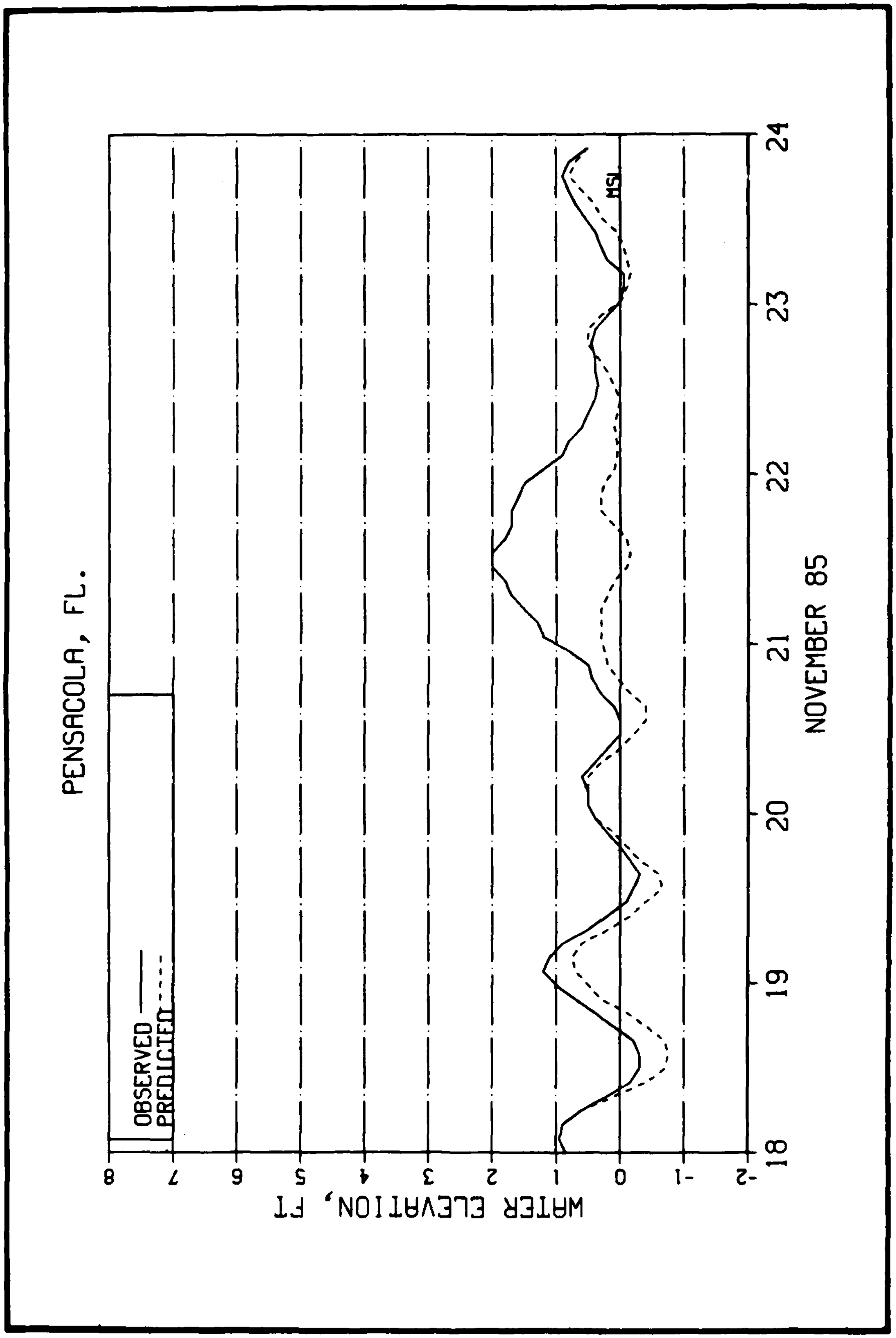
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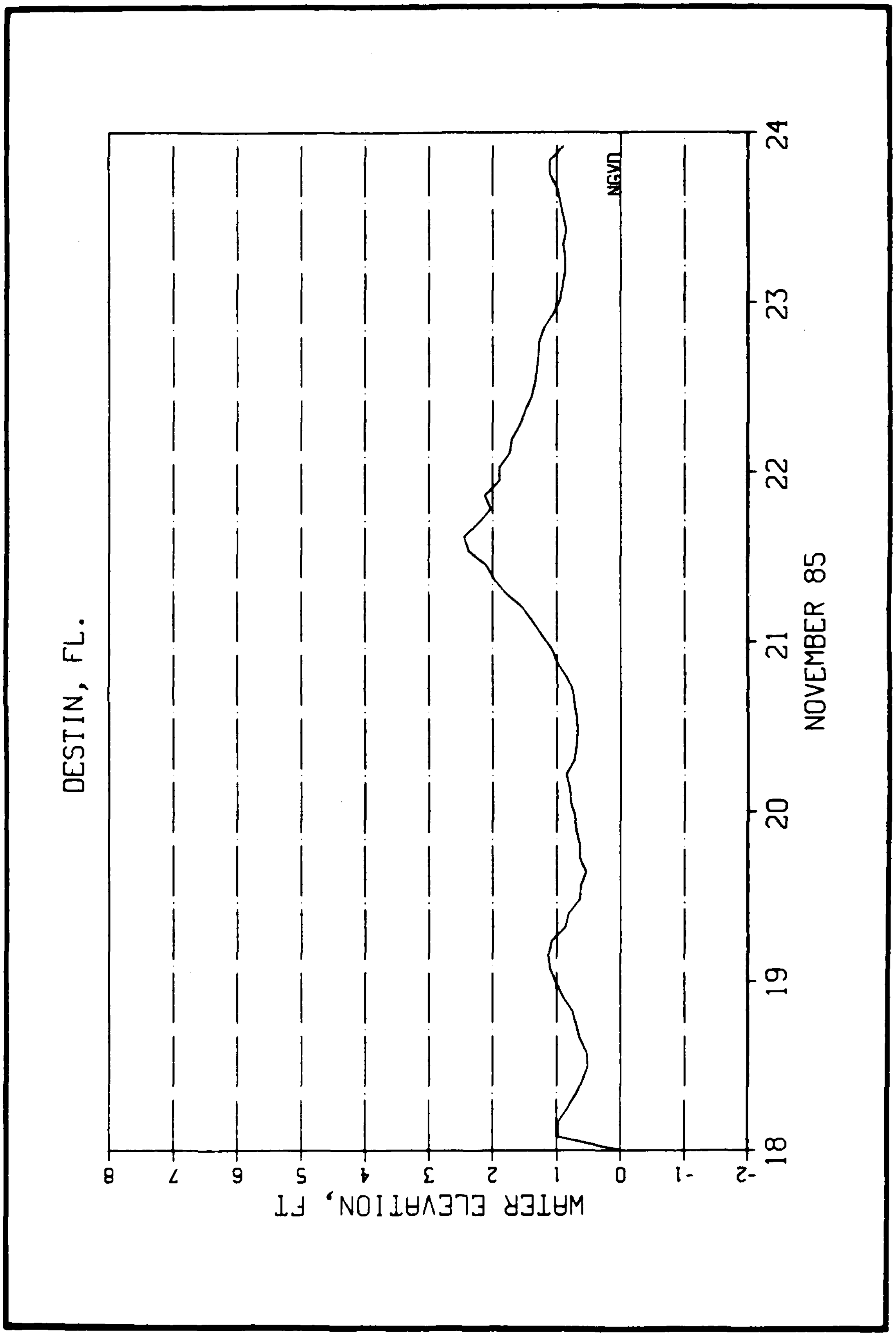
PLATE 1


DESTIN, FL.
WATER ELEVATION, FT
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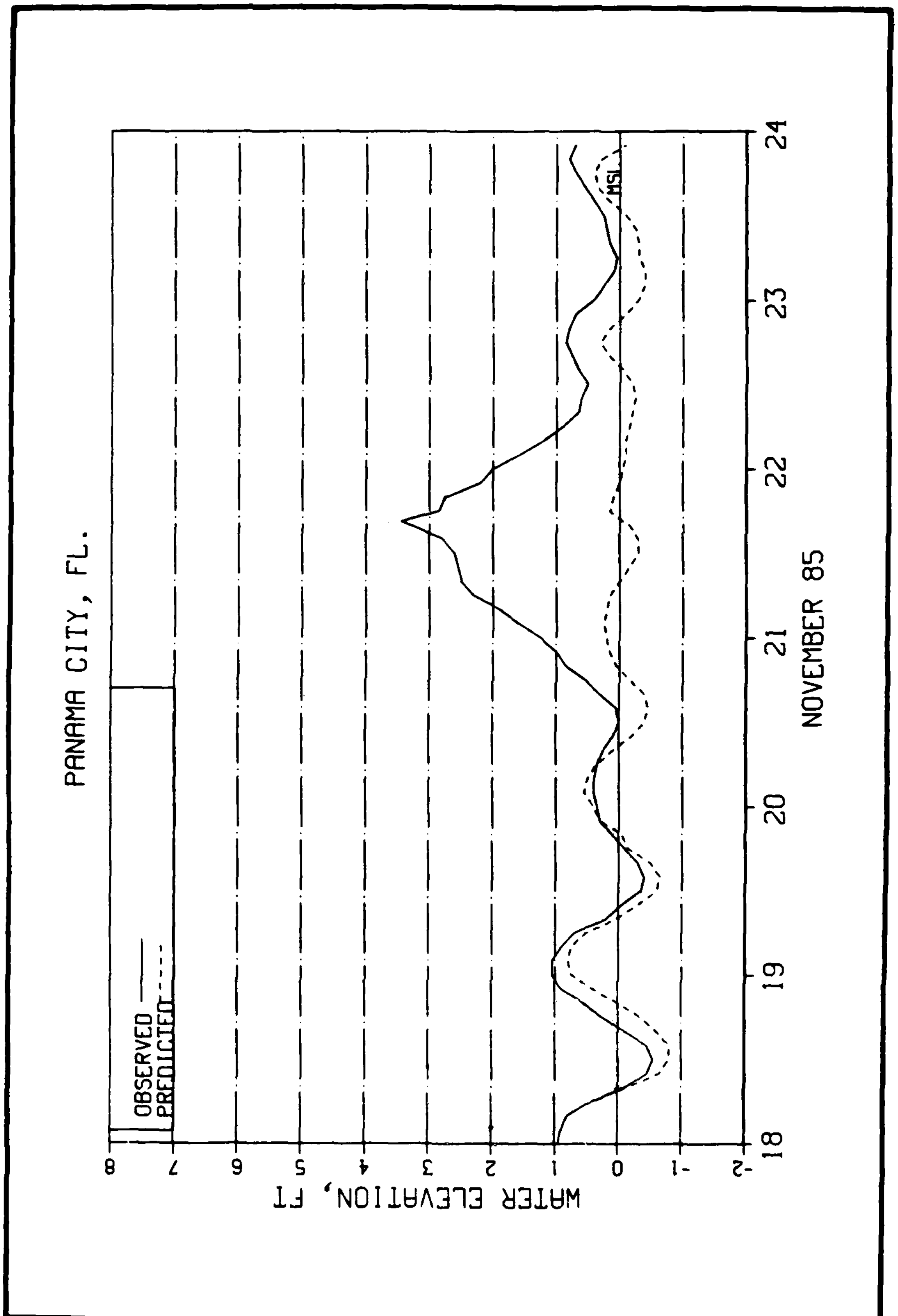
NOVEMBER 85

PLATE 2



PANAMA CITY, FL.
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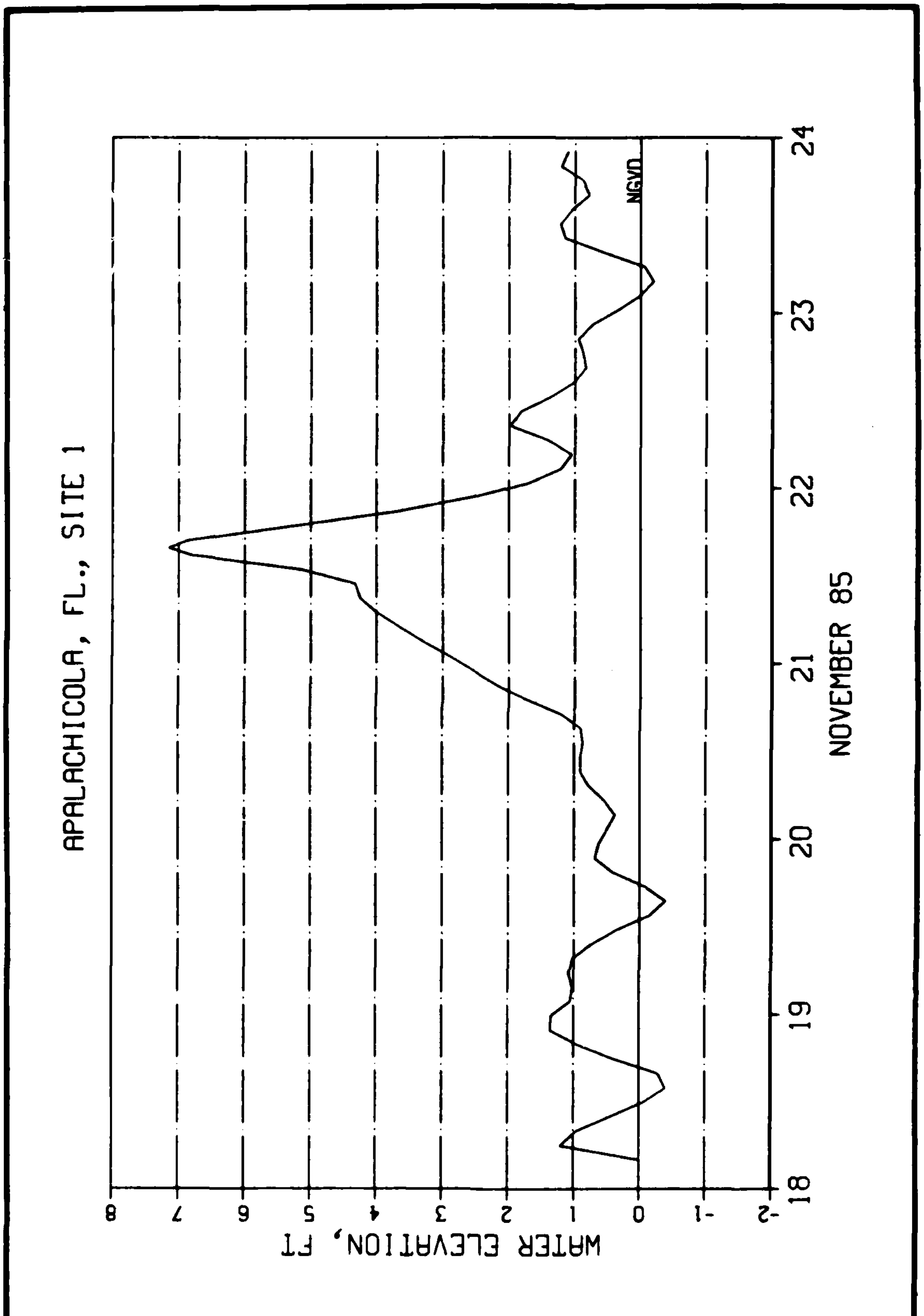
NOVEMBER 85

PLATE 3



APALACHICOLA, FL., SITE 1
WATER ELEVATION, FT
NOVEMBER 85
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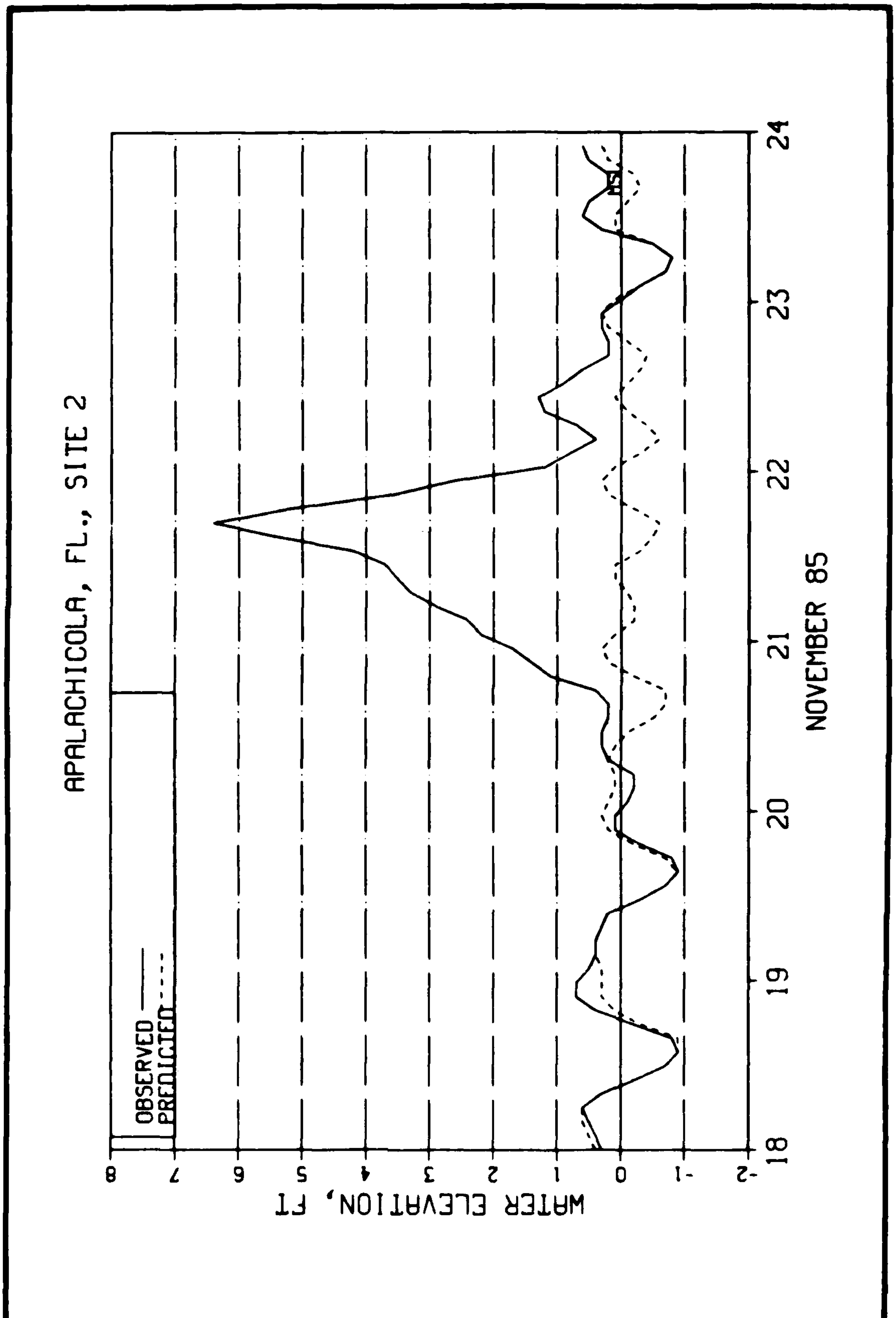
PLATE 4



APALACHICOLA, FL., SITE 2
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PREDICTED
WATER ELEVATION, FT
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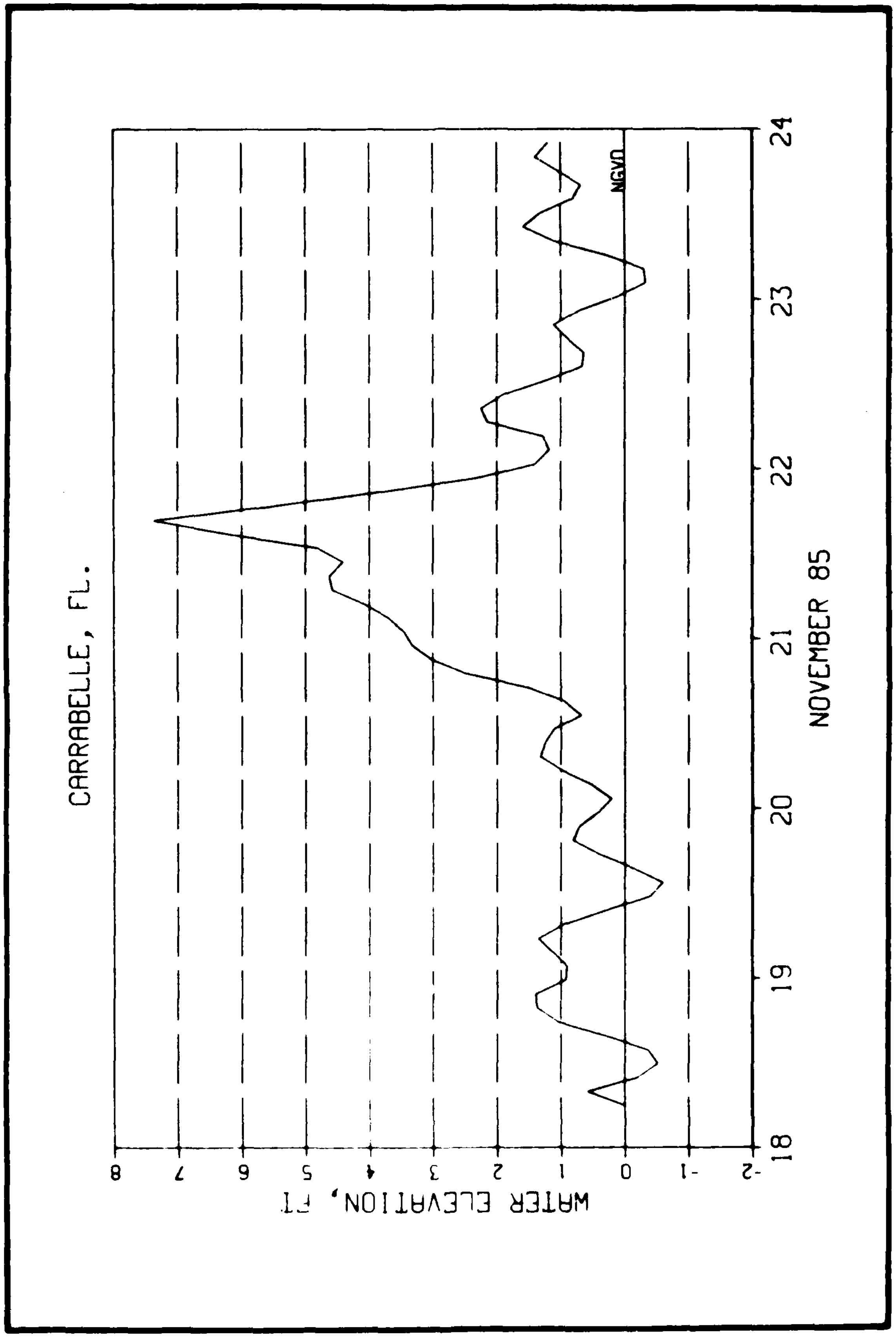
NOVEMBER 85

PLATE 5


CARRABELLE, FL.
NOVEMBER 85
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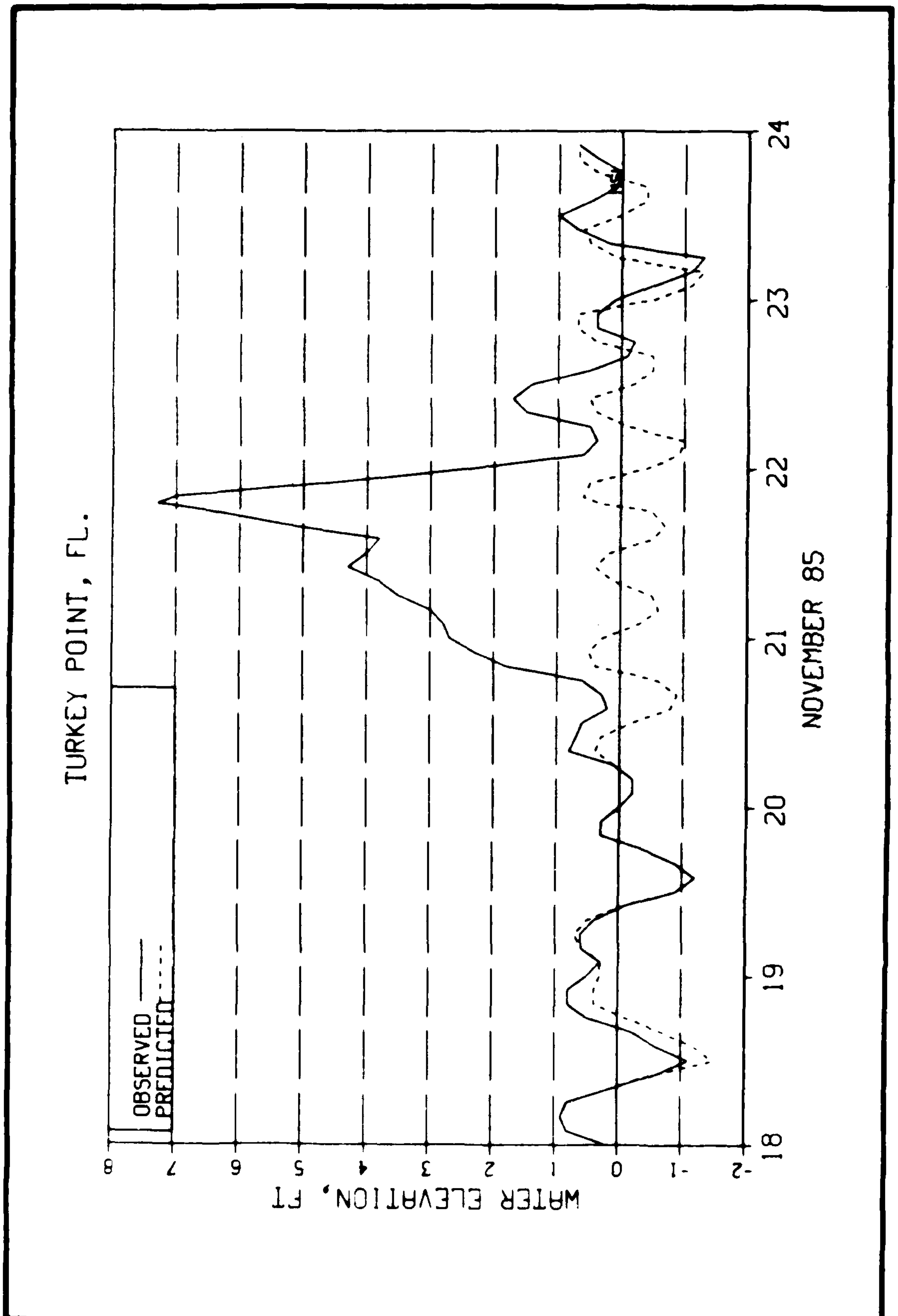
NGVD

PLATE 6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NOVEMBER 85
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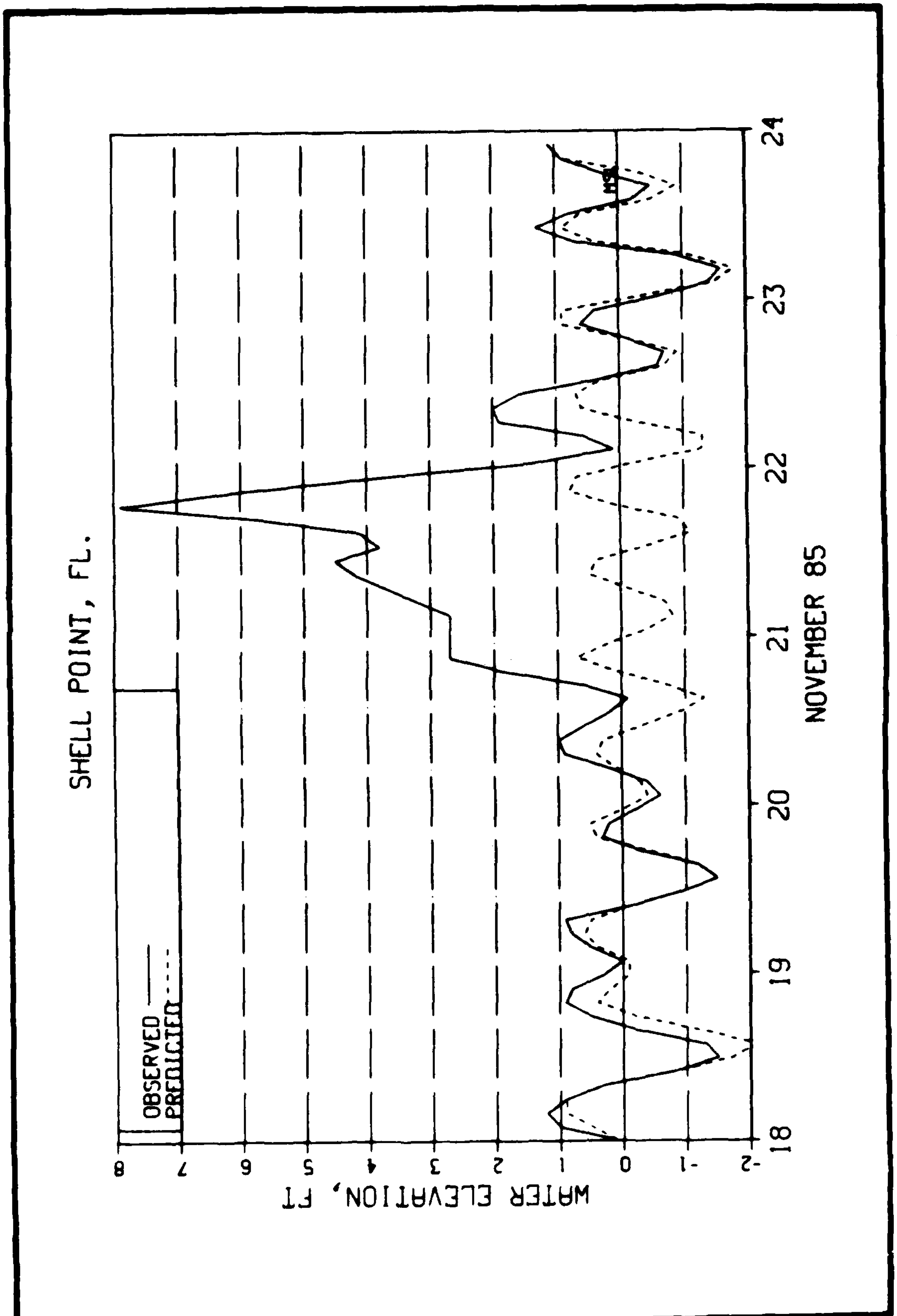
7
6
5
4
3
2
1
0
-1
-2
18
19
20
21
22
23
24

PLATE 7



SHELL POINT, FL.
OBSERVED
PREDICTED
WATER ELEVATION, FT
8
7
6
5
4
3
2
1
0
-1
-2
18
19
20
21
22
23
24
NOVEMBER 85

PLATE 8

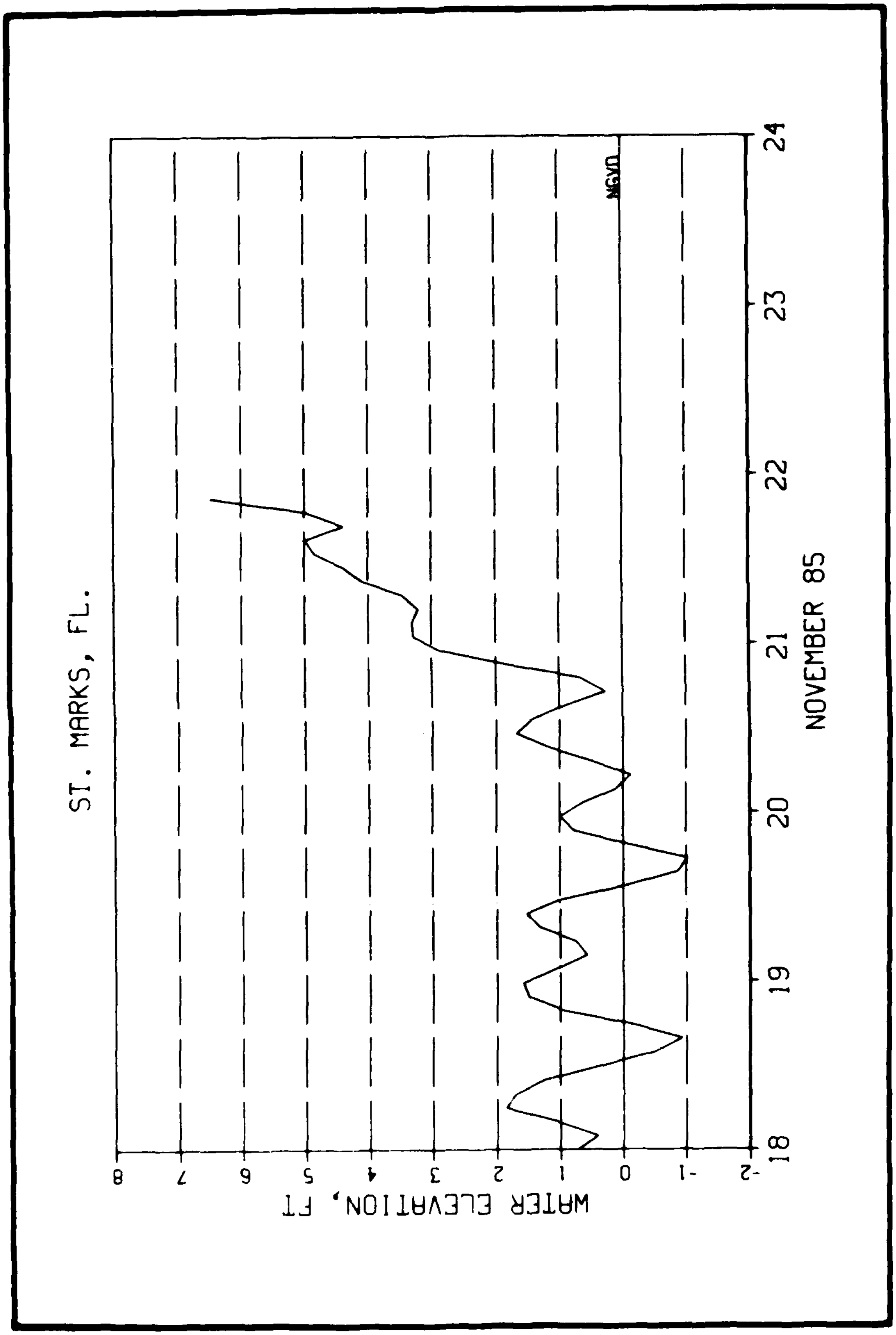

ST. MARKS, FL.
WATER ELEVATION, FT
8
7
6
5
4
3
2
1
0
-1
-2
NGVD
18
19
20
21
22
23
24
NOVEMBER 85

PLATE 9

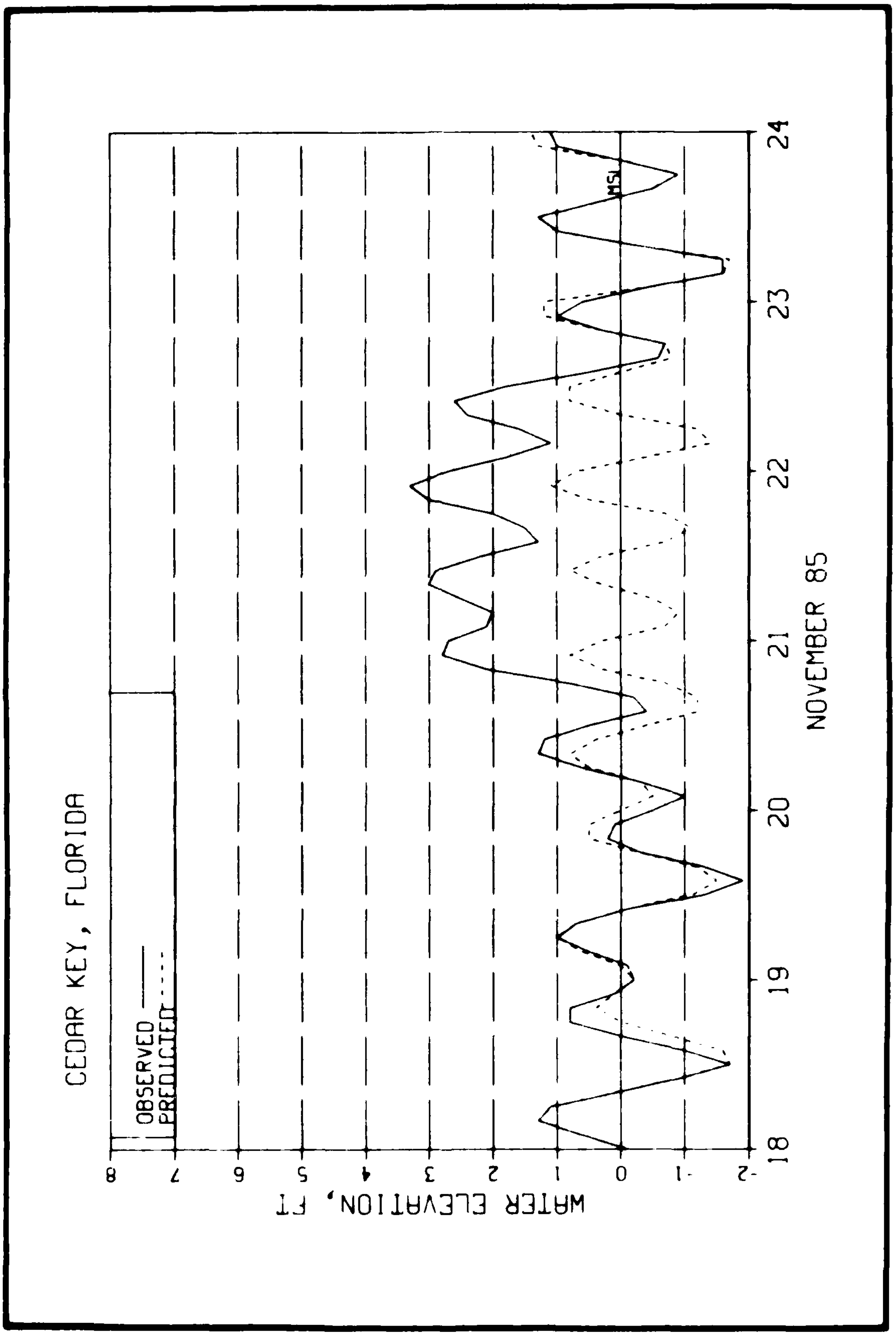

CEDAR KEY, FLORIDA
OBSERVED
PREDICTED
WATER ELEVATION, FT
8
7
6
5
4
3
2
1
0
-1
-2
MSL
18
19
20
21
22
23
24
NOVEMBER 85

PLATE 10

APPENDIX A: HIGH-WATER CONTOUR MAPS

This appendix contains a series of contour maps which are segments of US Geological Survey maps of the area. All of the segments were taken from 1/24,000-scale maps which were reproduced at 65 percent of their original size, resulting in a 1/37,000 scale for the contour map segments in this appendix. Each map segment covers an area approximately 4 miles by 5 miles. All of the map segments have a contour interval of 2 m, except for segments 40 and 43 which have a contour interval of 5 ft. High-water marks surveyed by the US Army Engineer District, Mobile, are plotted on these maps. Not all maps contain a high-water mark but are included for reasons of continuity. The elevations of the high-water marks are labeled in metres above National Geodetic Vertical Datum (NGVD) except for segment 43, which is labeled in feet above NGVD. All high-water marks are denoted by a ● symbol.

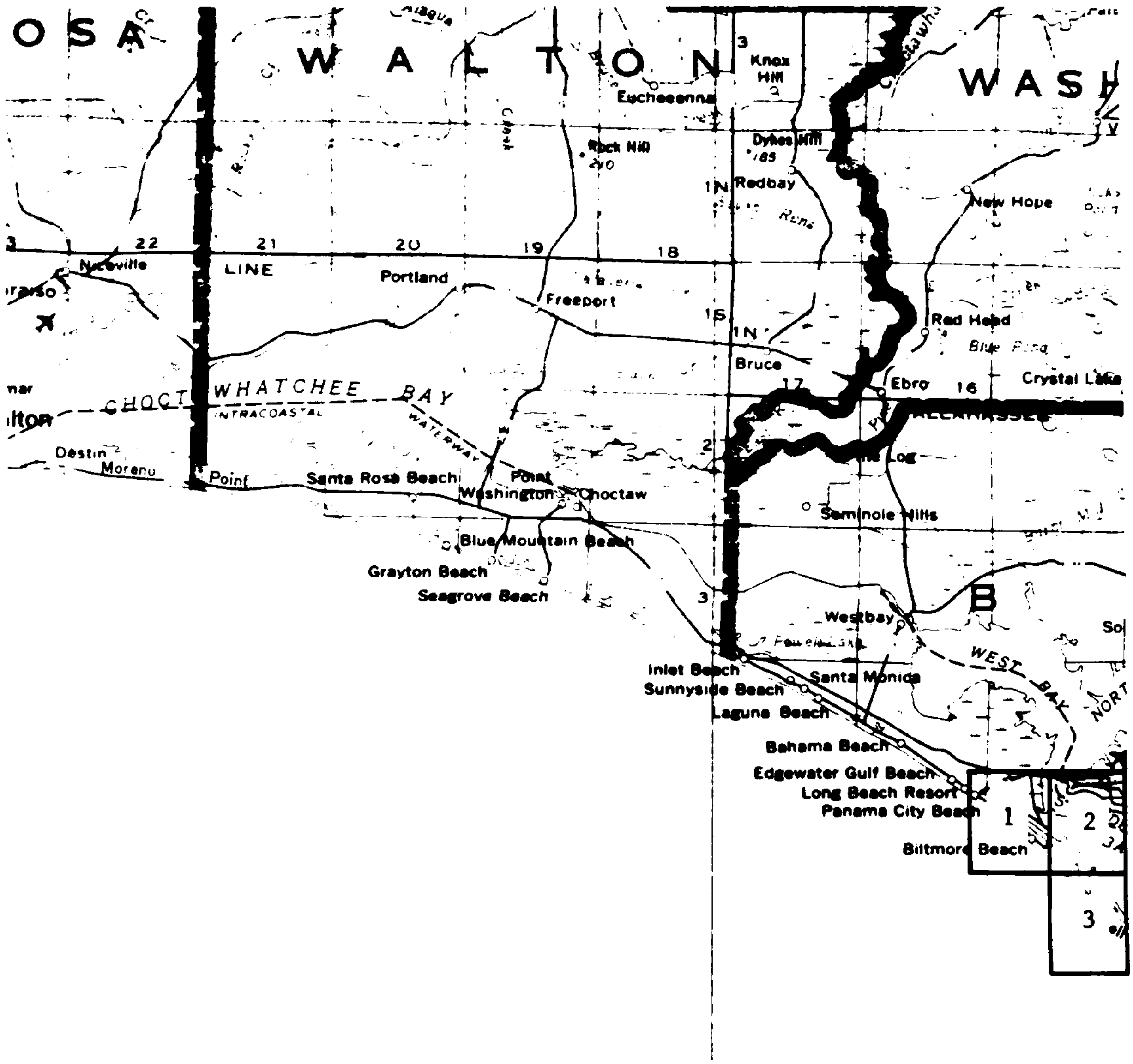


Figure A1. Index to high-water contour maps, segments 1-3

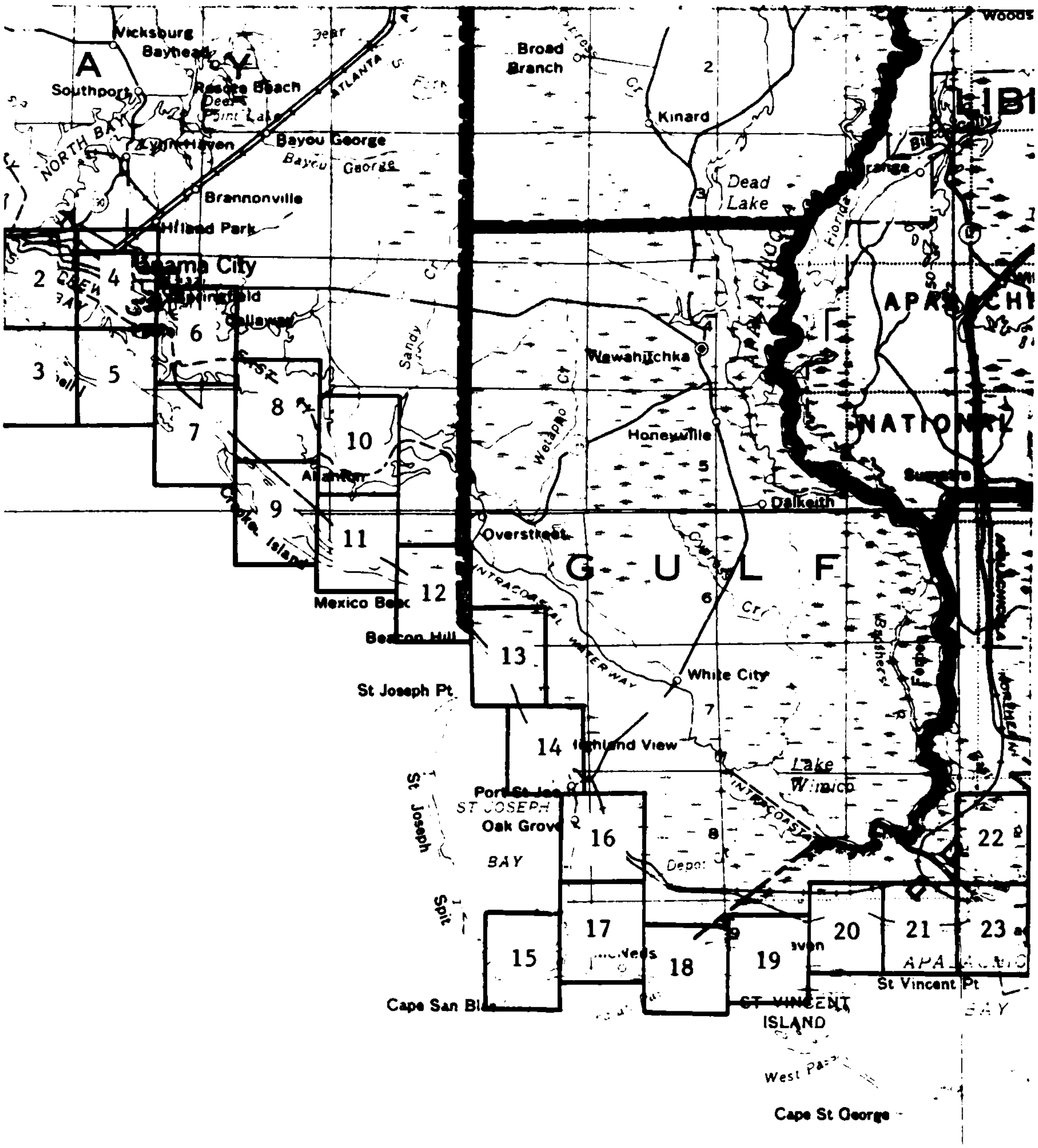


Figure A2. Index to high-water contour maps, segments 2-23

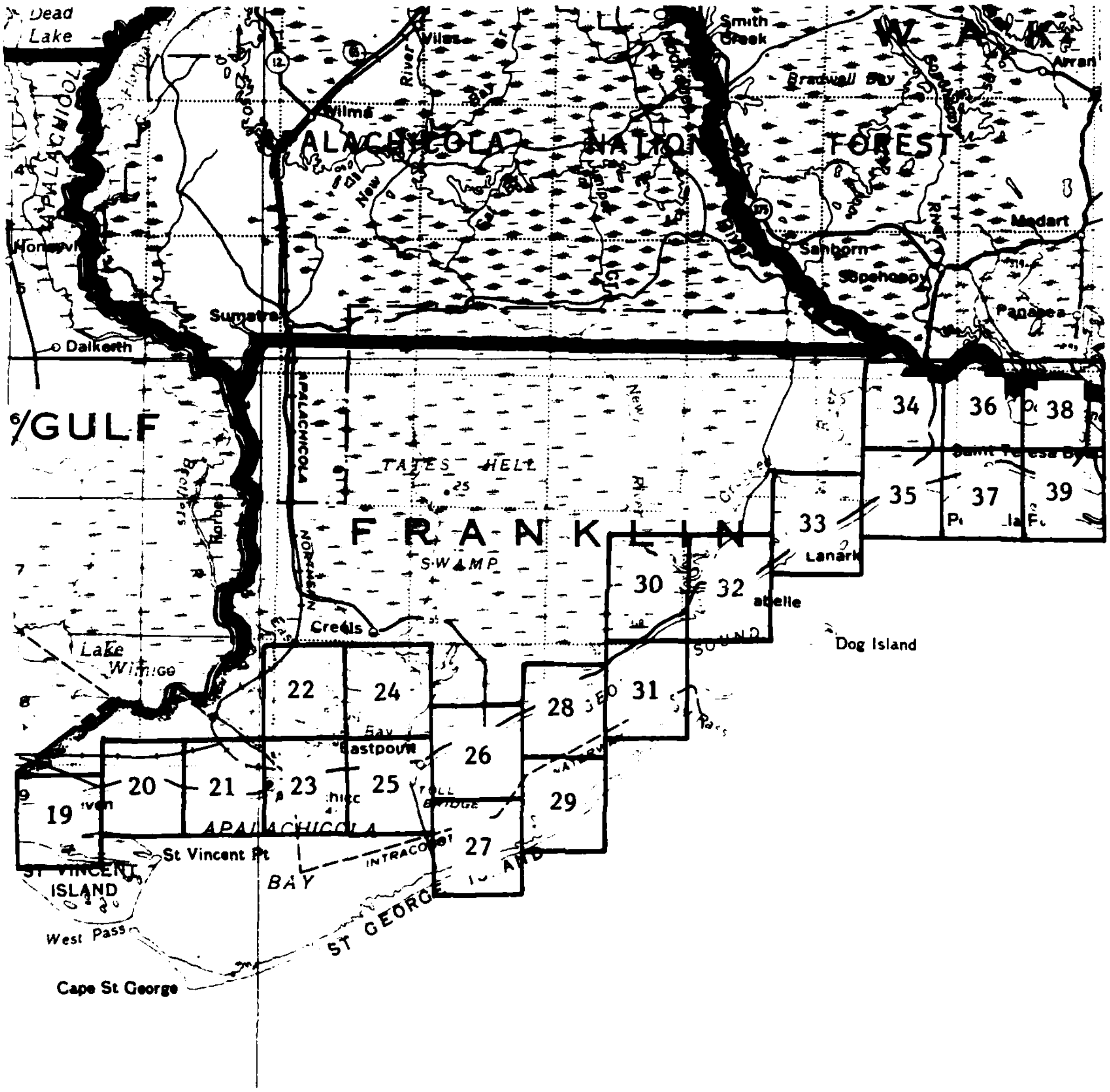


Figure A3. Index to high-water contour maps, segments 19-39

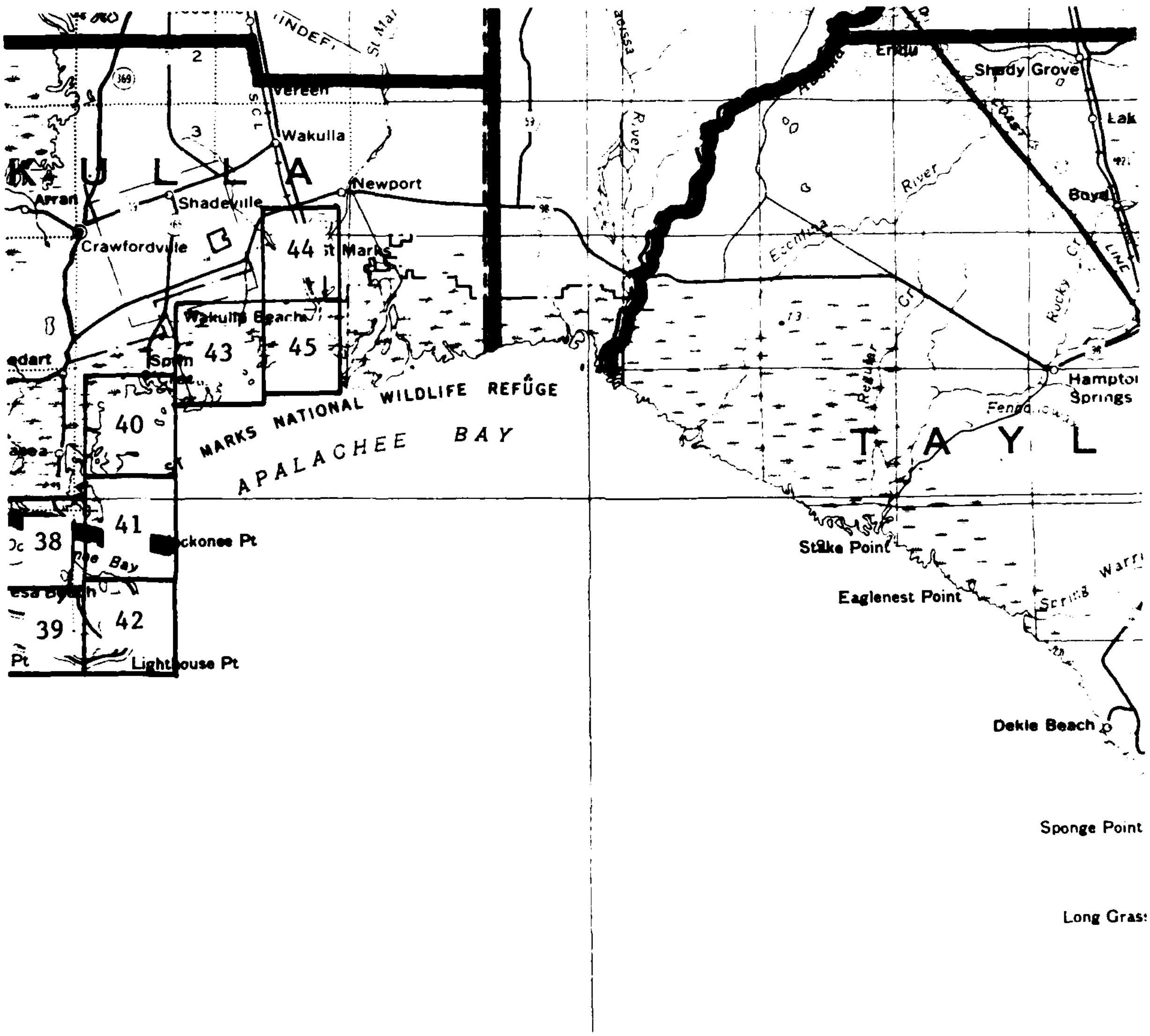


Figure A4. Index to high-water contour maps, segments 38-45

Figure A5. Segment 1

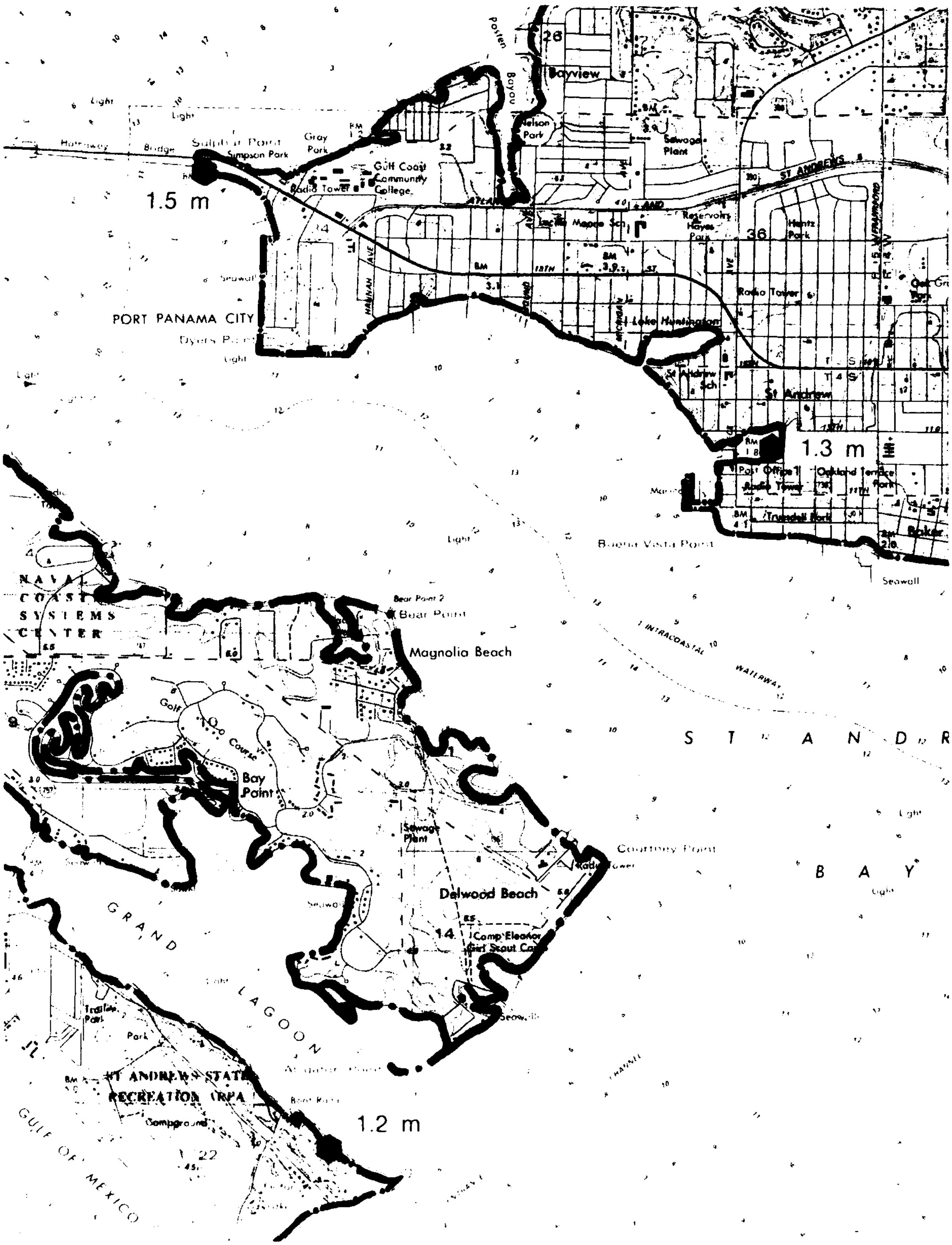


Figure A6. Segment 2

Figure A7. Segment 3

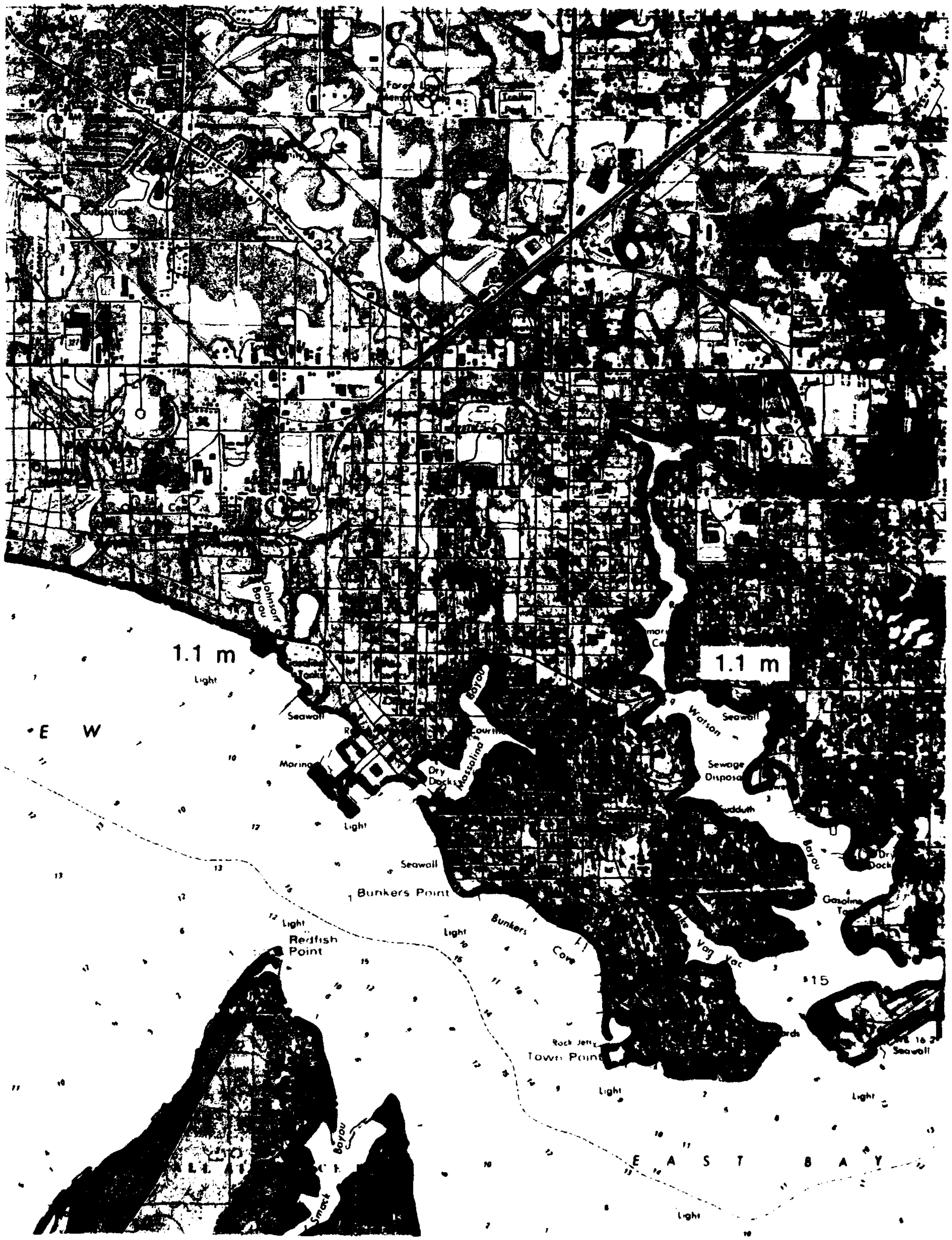


Figure A8. Segment 4

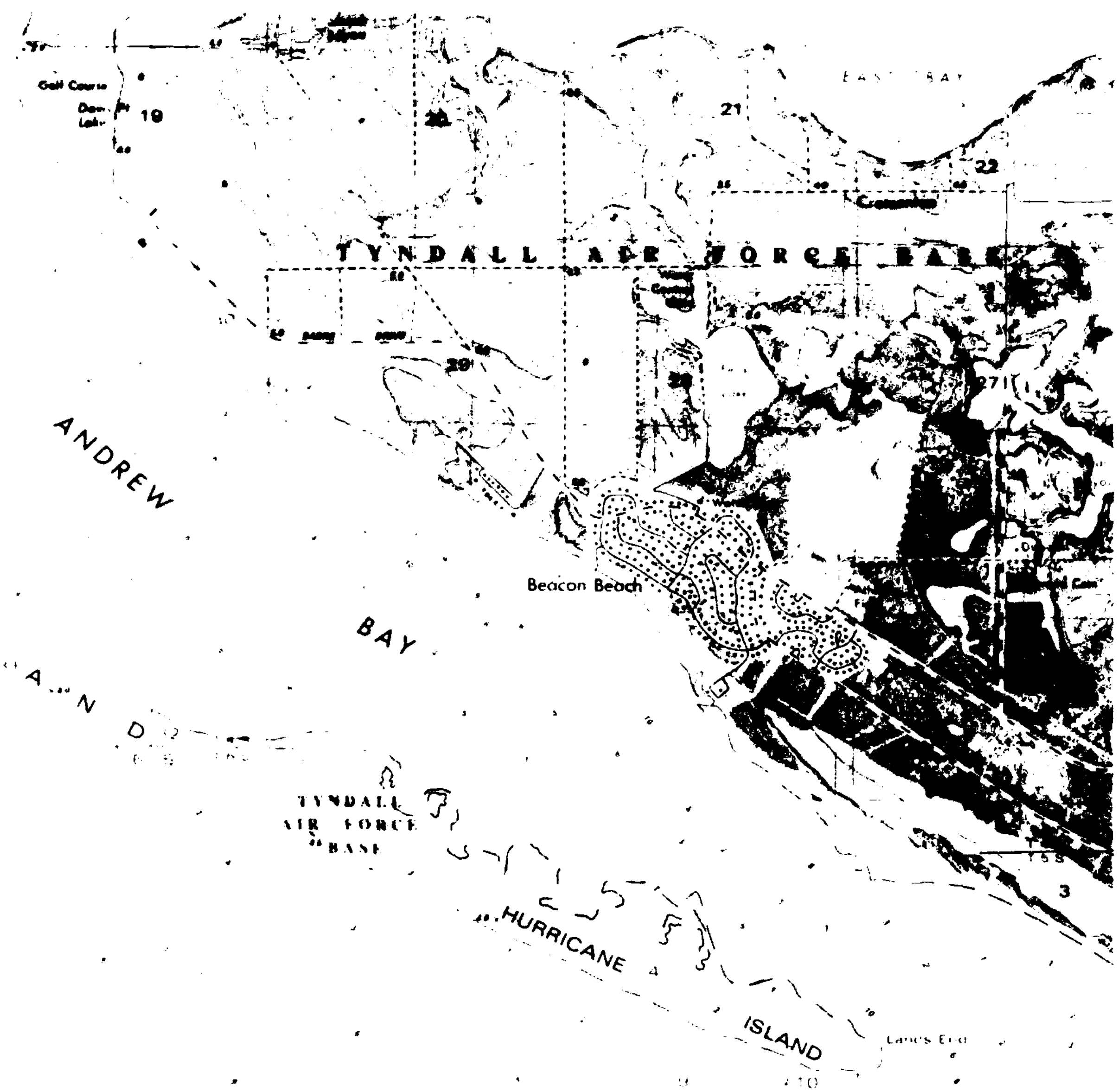


Figure A9. Segment 5

Figure A10. Segment 6

Figure A11. Segment 7

Figure A12. Segment 8

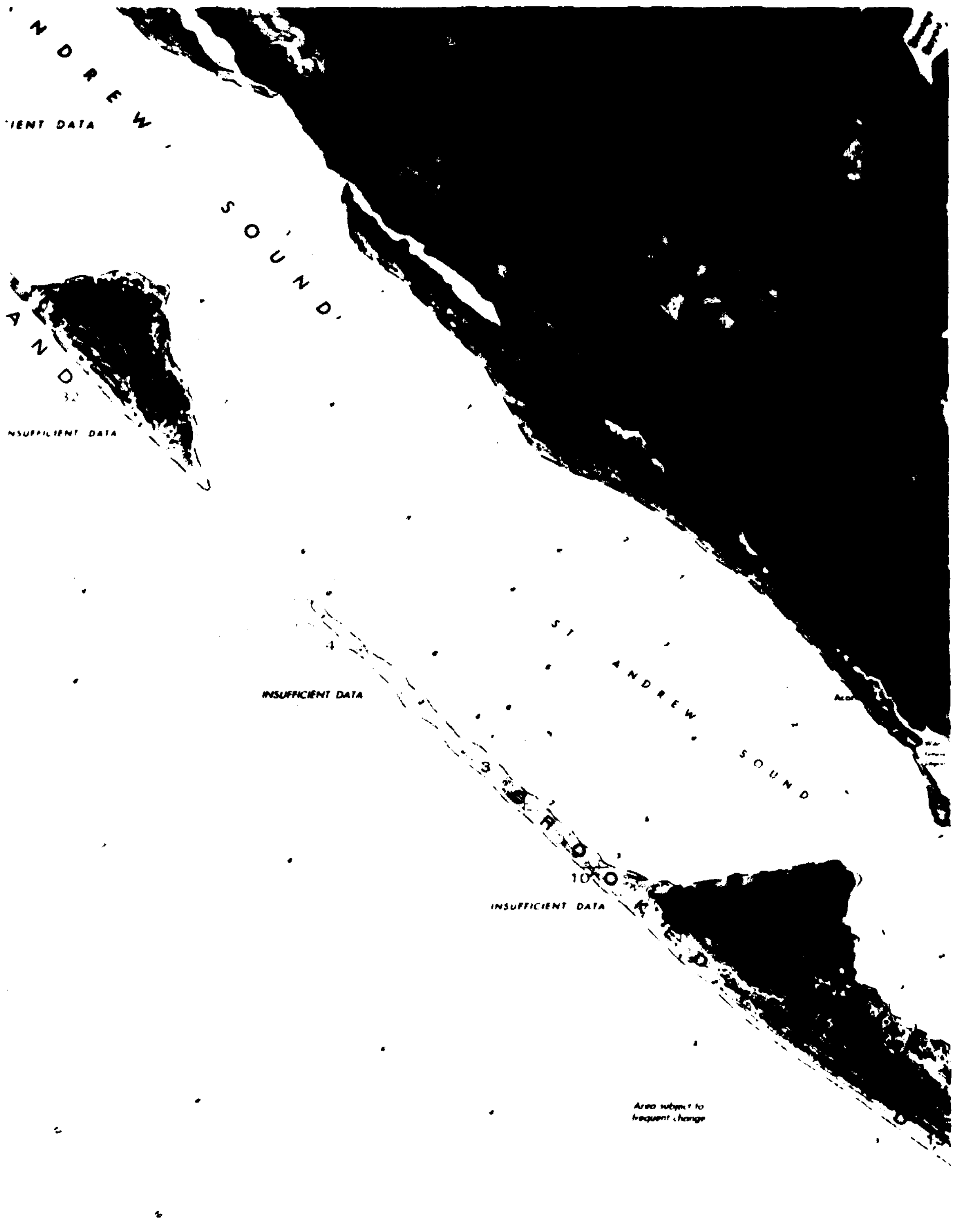


Figure A13. Segment 9

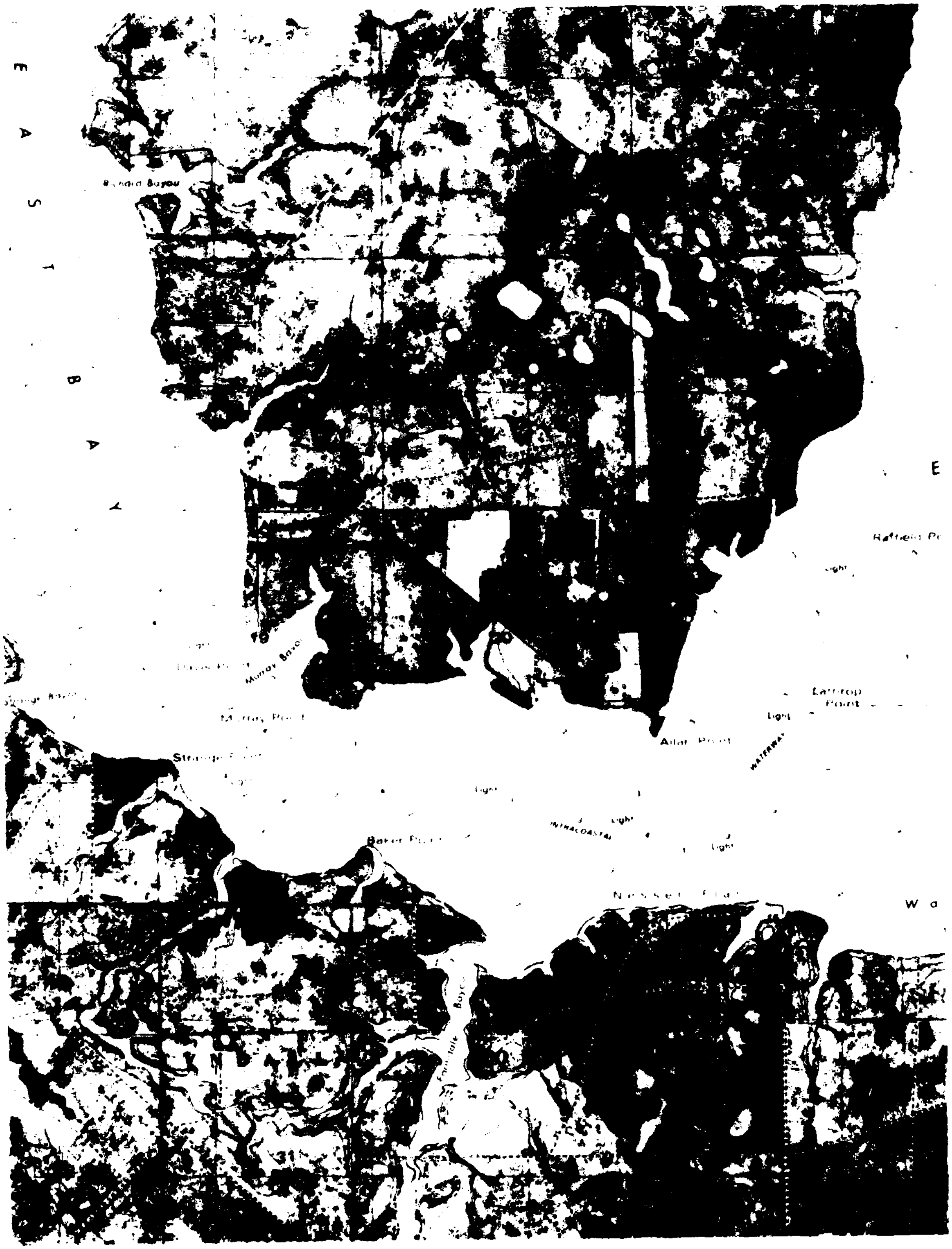


Figure A14. Segment 10

Figure A15. Segment 11

Figure A16. Segment 12

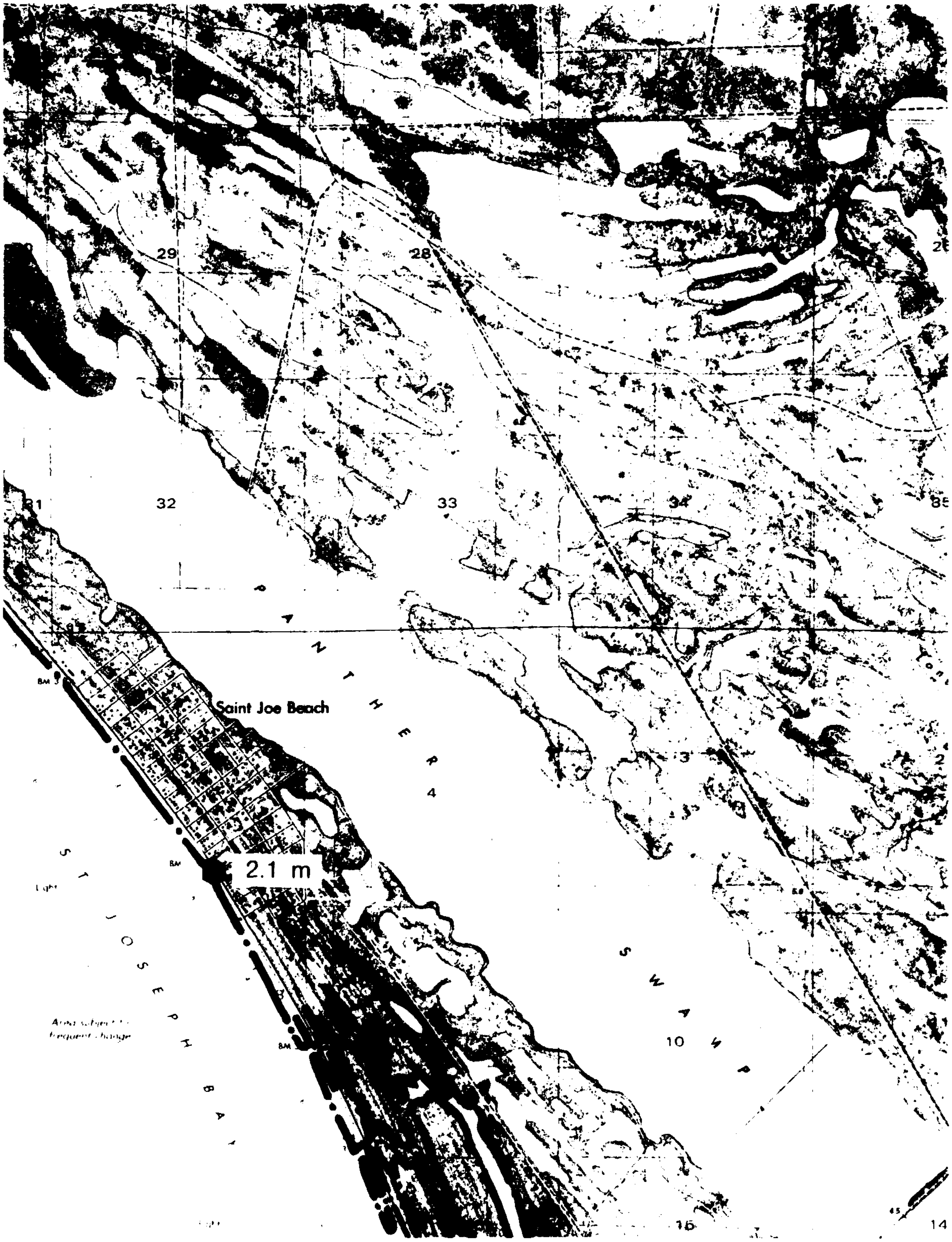


Figure A17. Segment 13

Figure A18. Segment 14

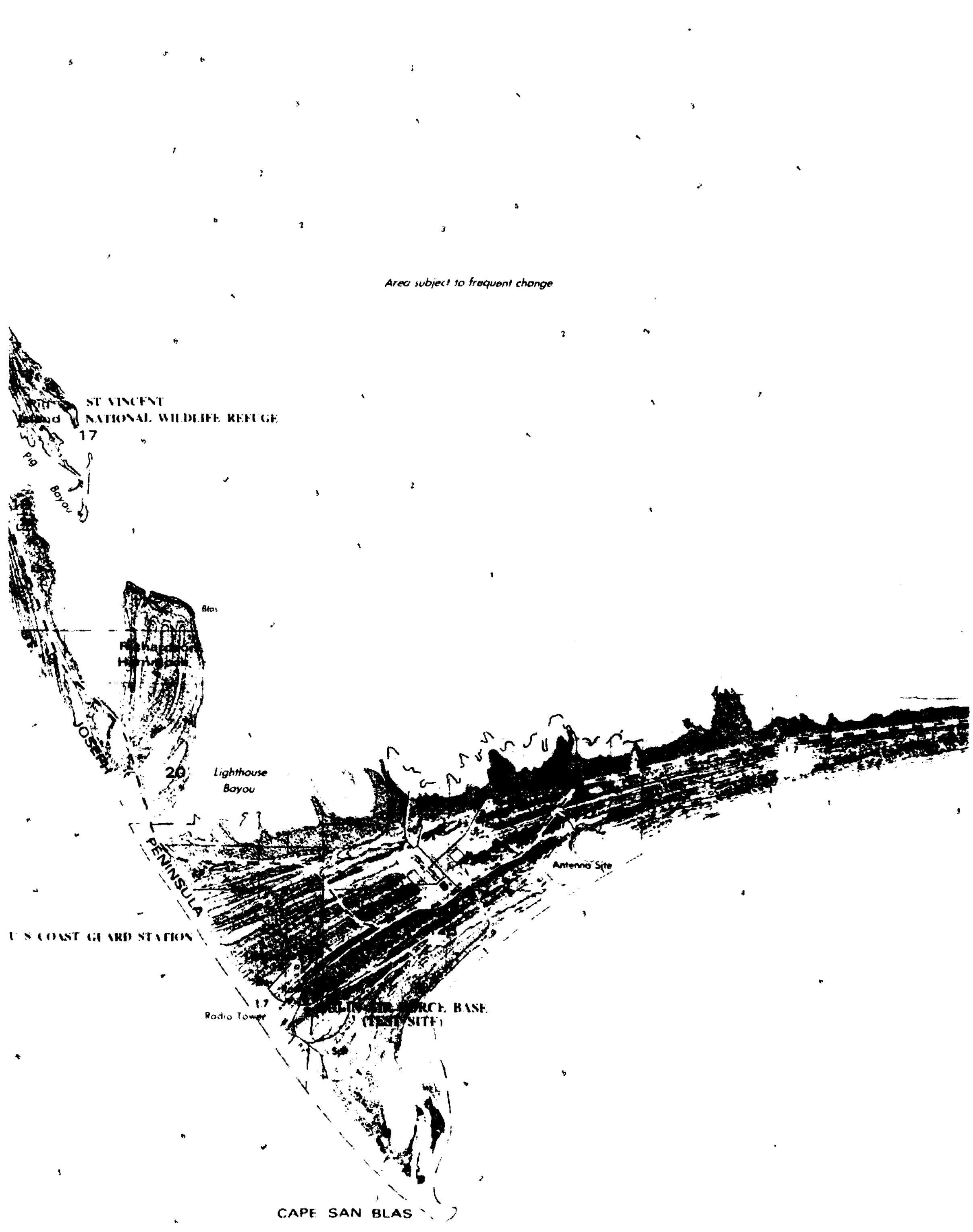


Figure A19. Segment 15

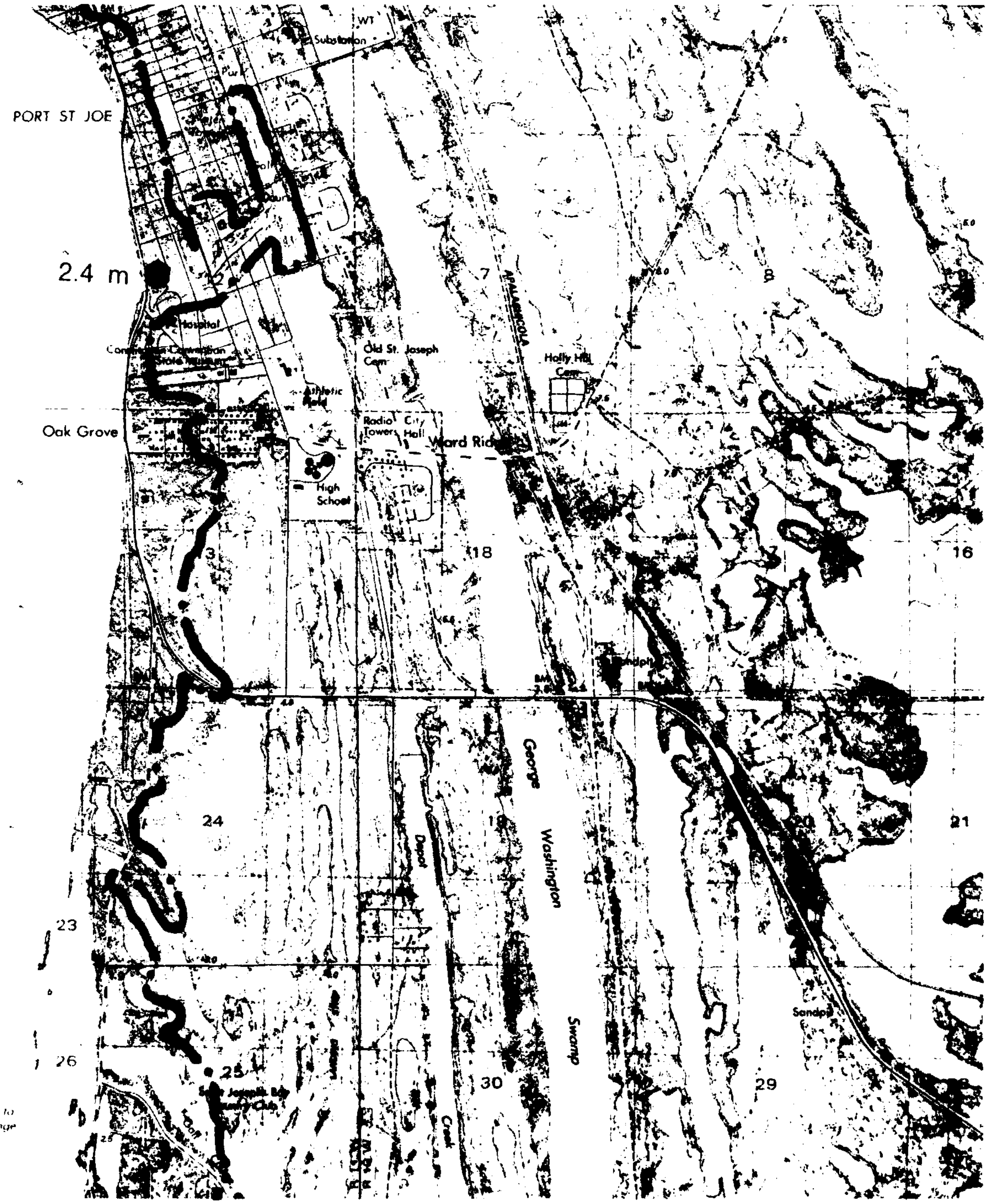


Figure A20. Segment 16

Figure A21. Segment 17

Figure A30. Segment 26

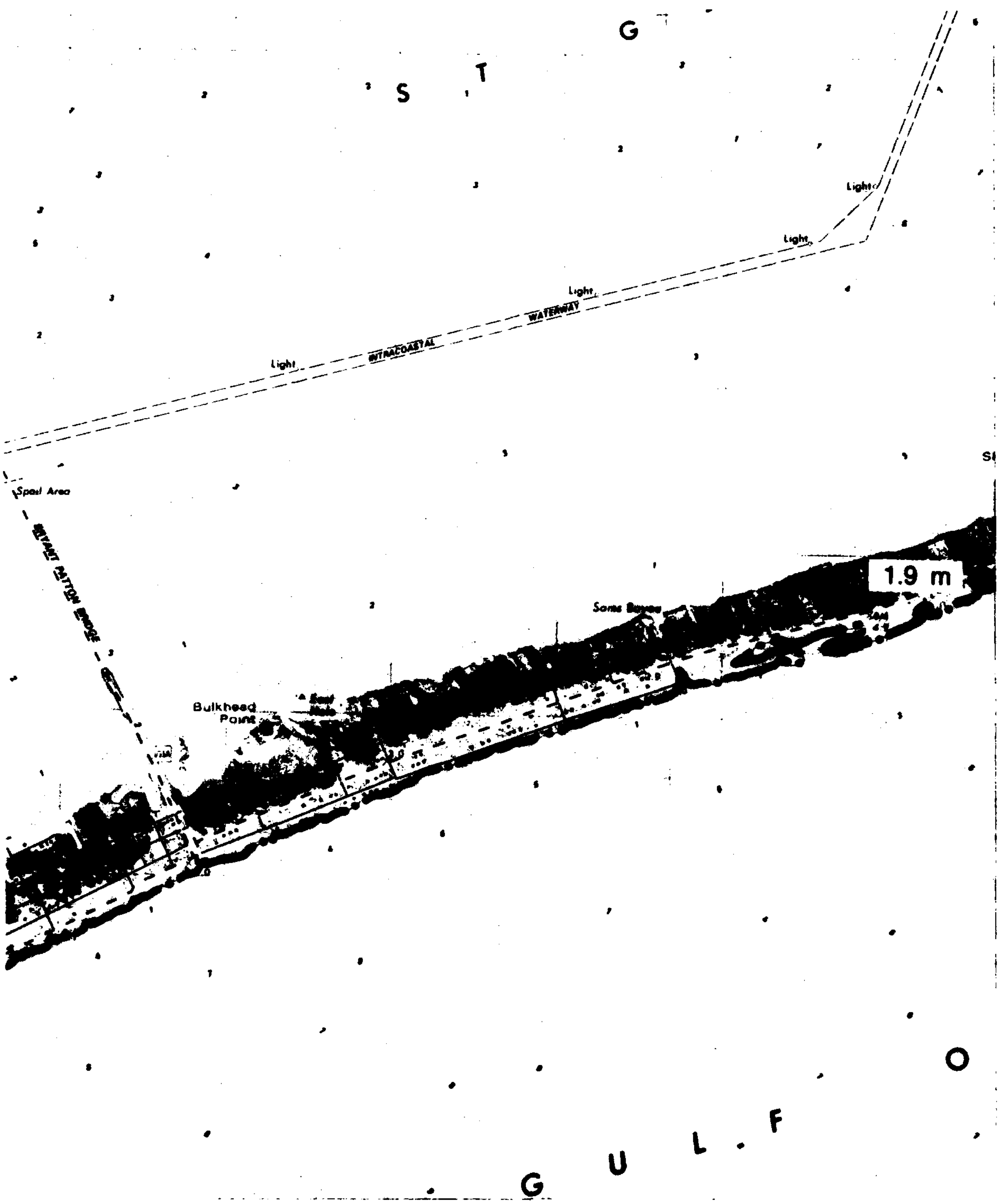


Figure A31. Segment 27

Figure A32. Segment 28

Figure A33. Segment 29

Figure A34. Segment 30

Figure A35. Segment 31

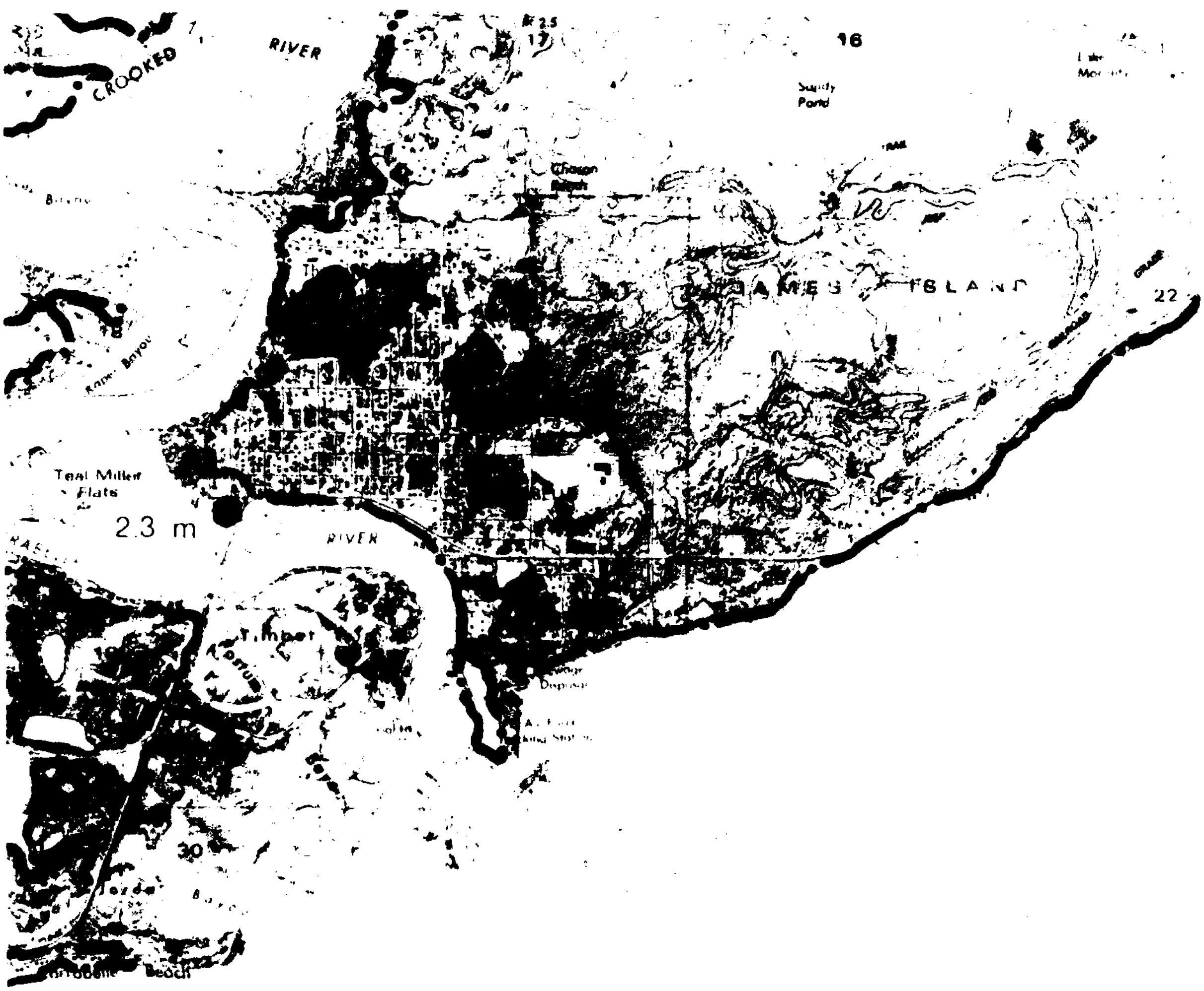


Figure A36. Segment 32

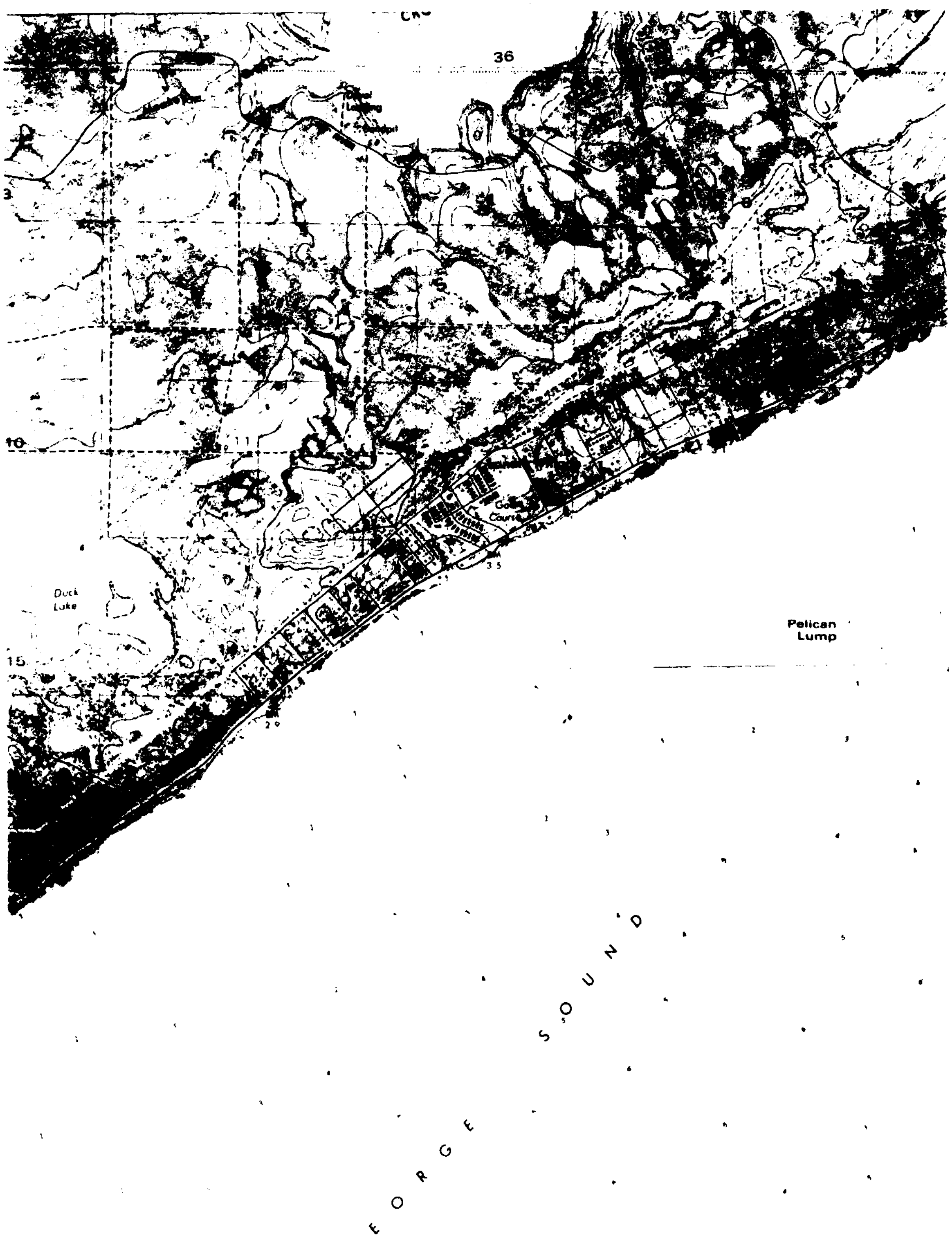


Figure A37. Segment 33

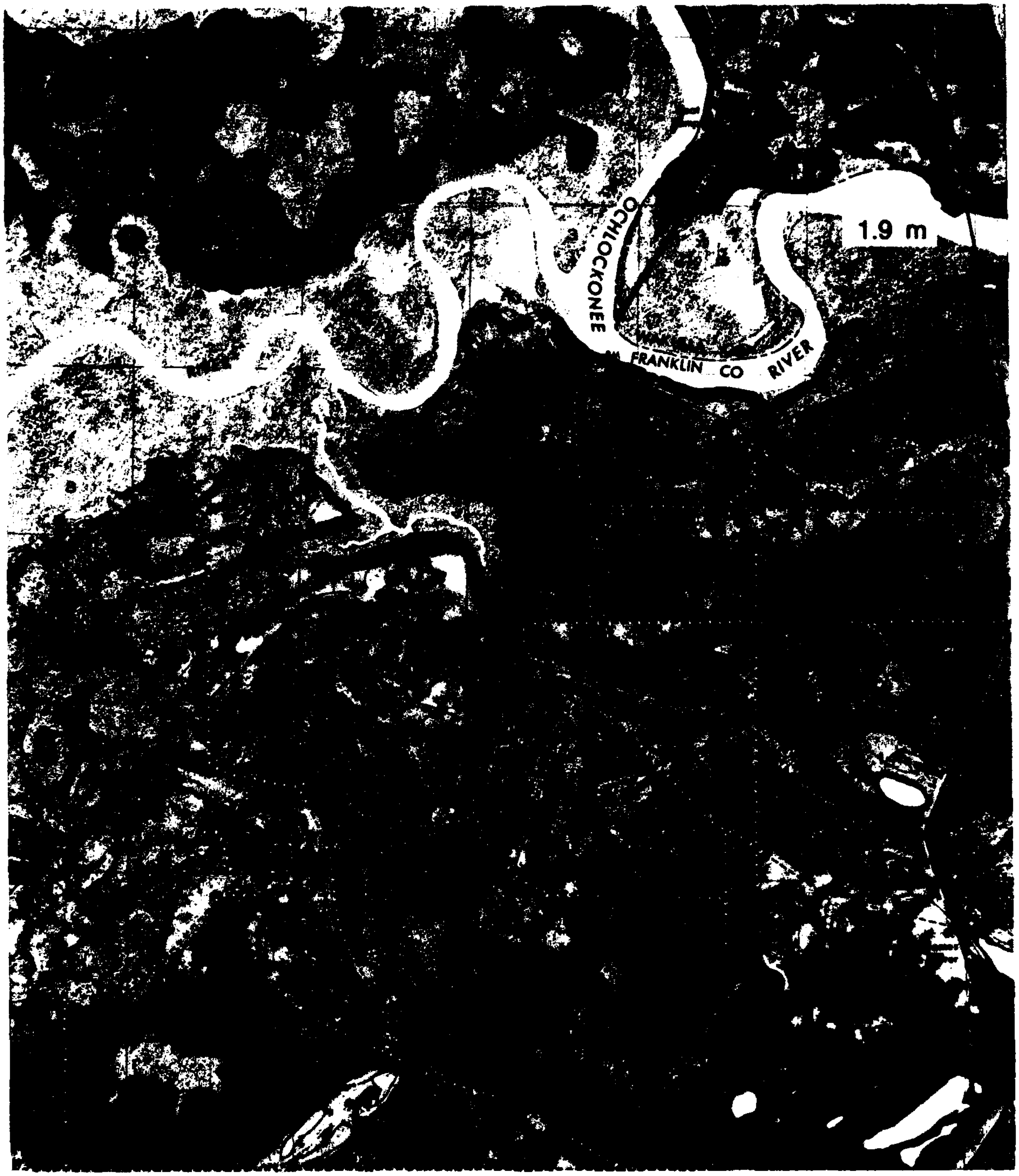


Figure A38. Segment 34

Figure A39. Segment 35

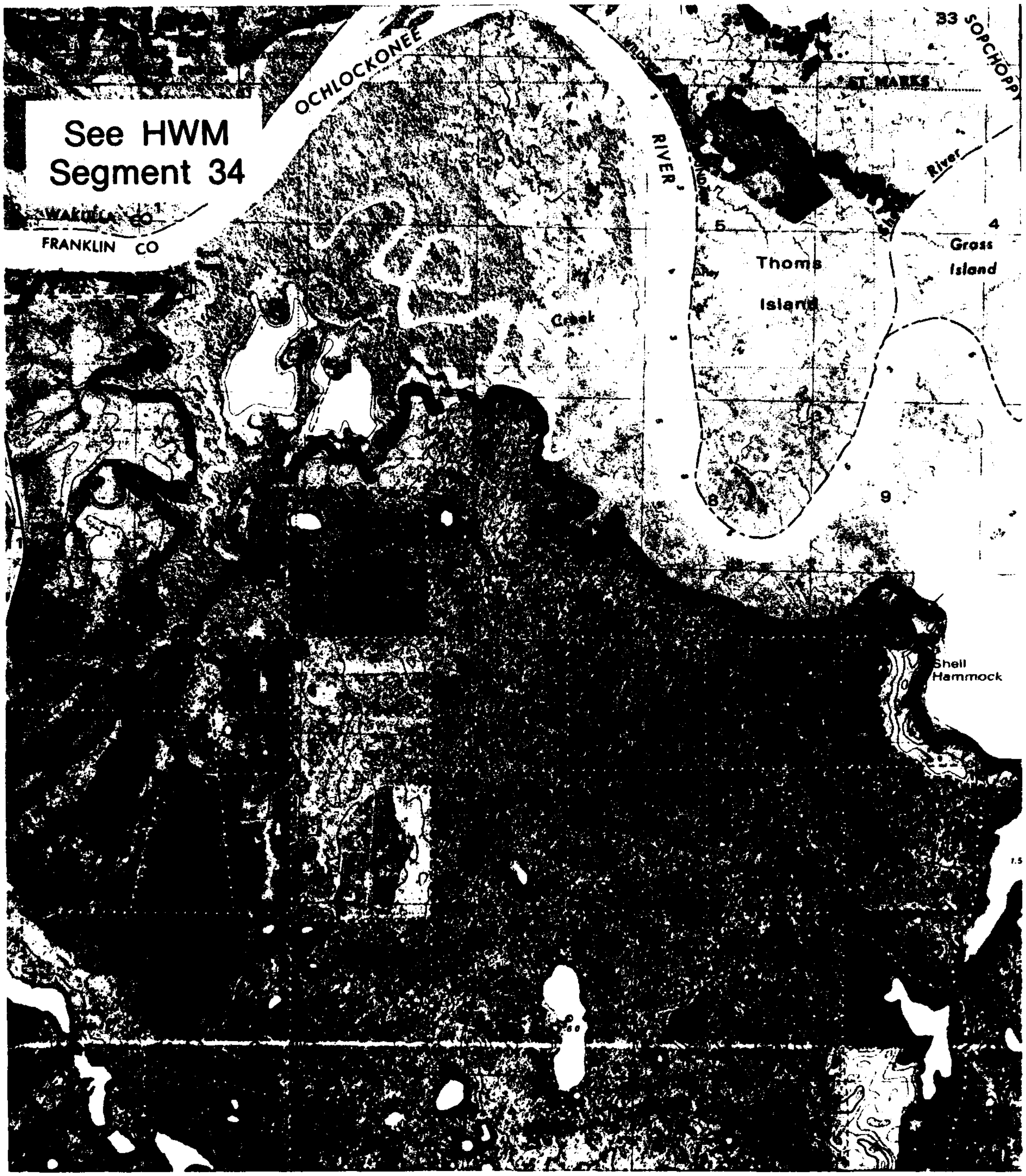


Figure A40. Segment 36

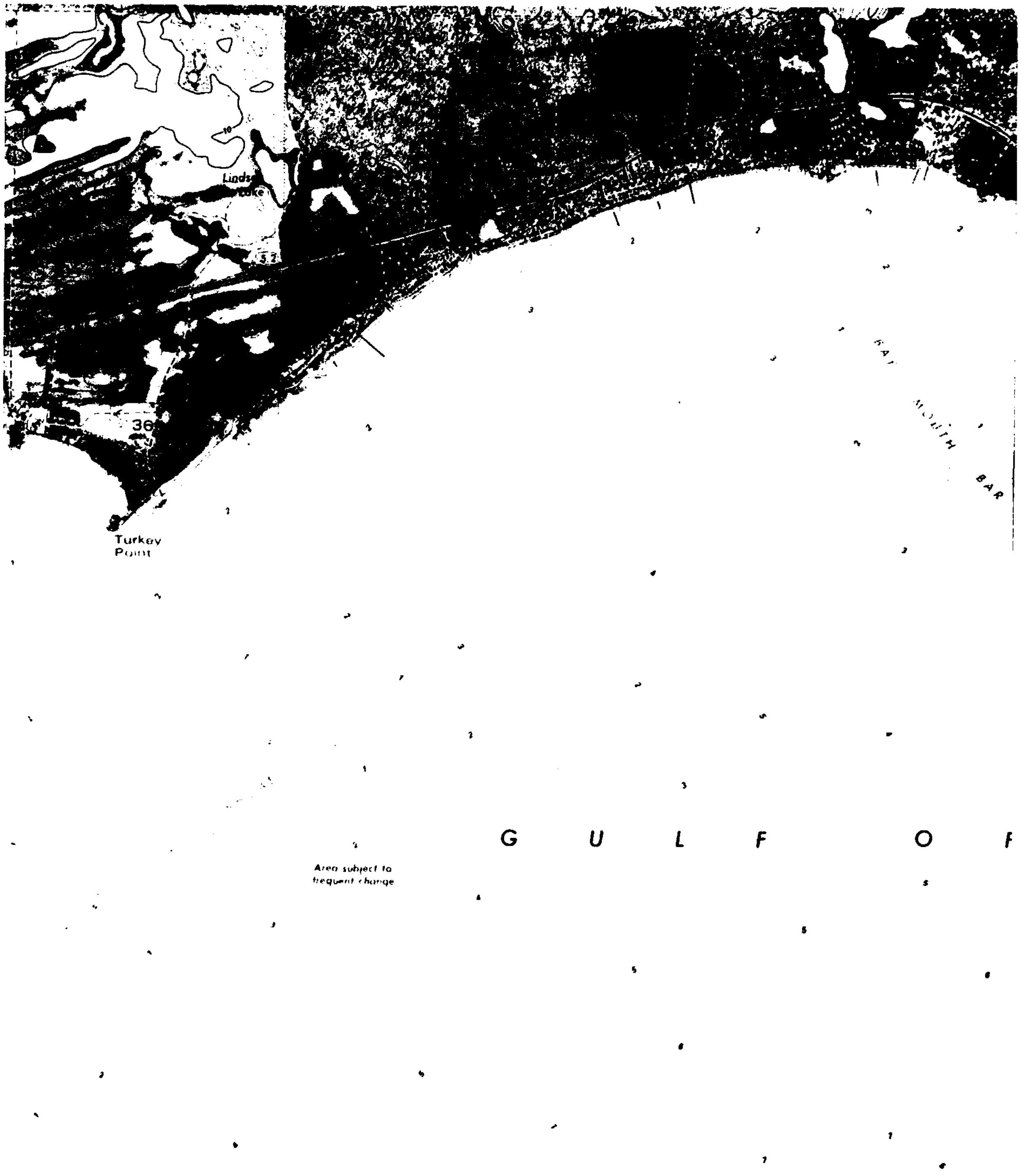


Figure A41. Segment 37

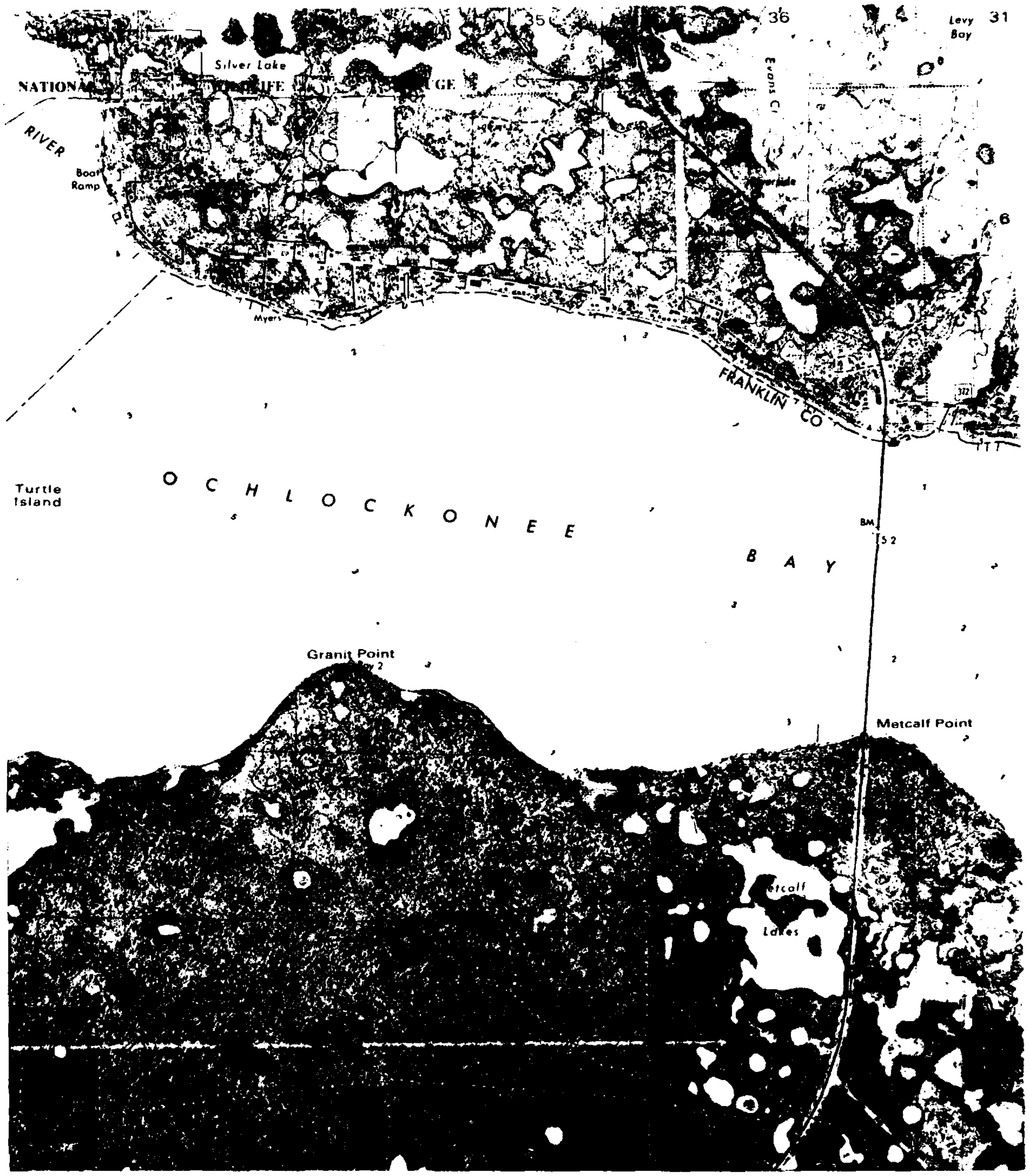


Figure A42. Segment 38

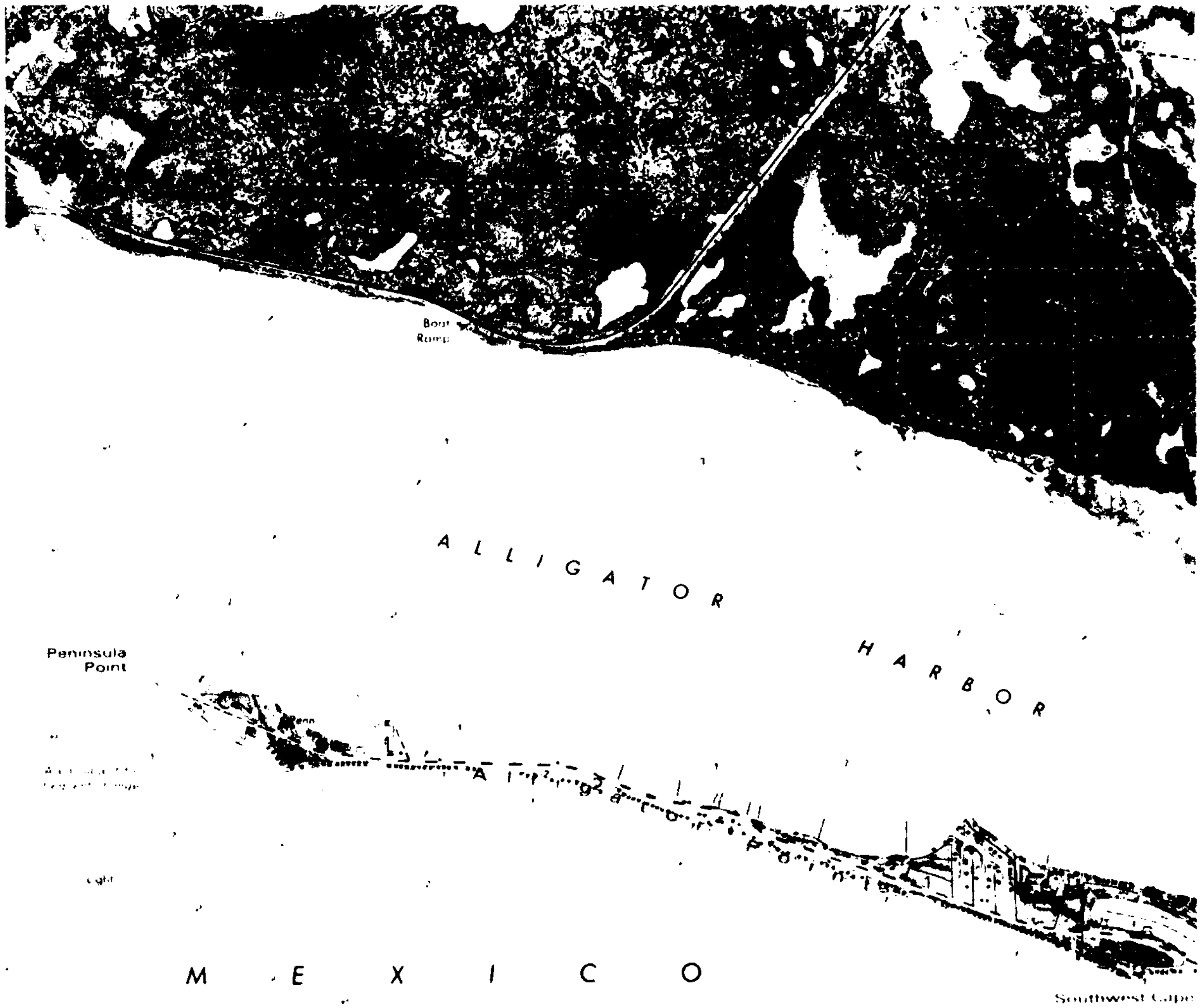


Figure A43. Segment 39

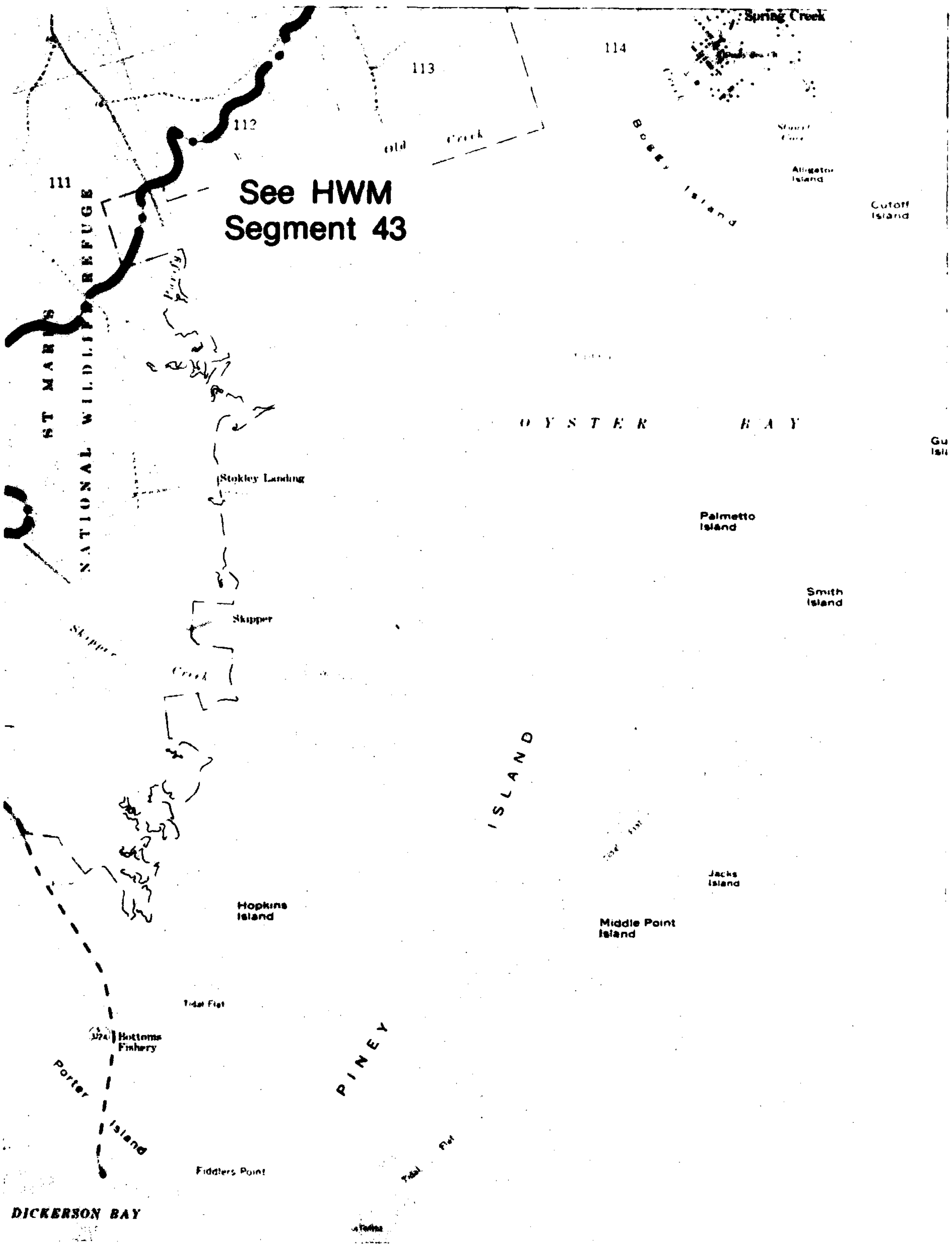


Figure A44. Segment 40

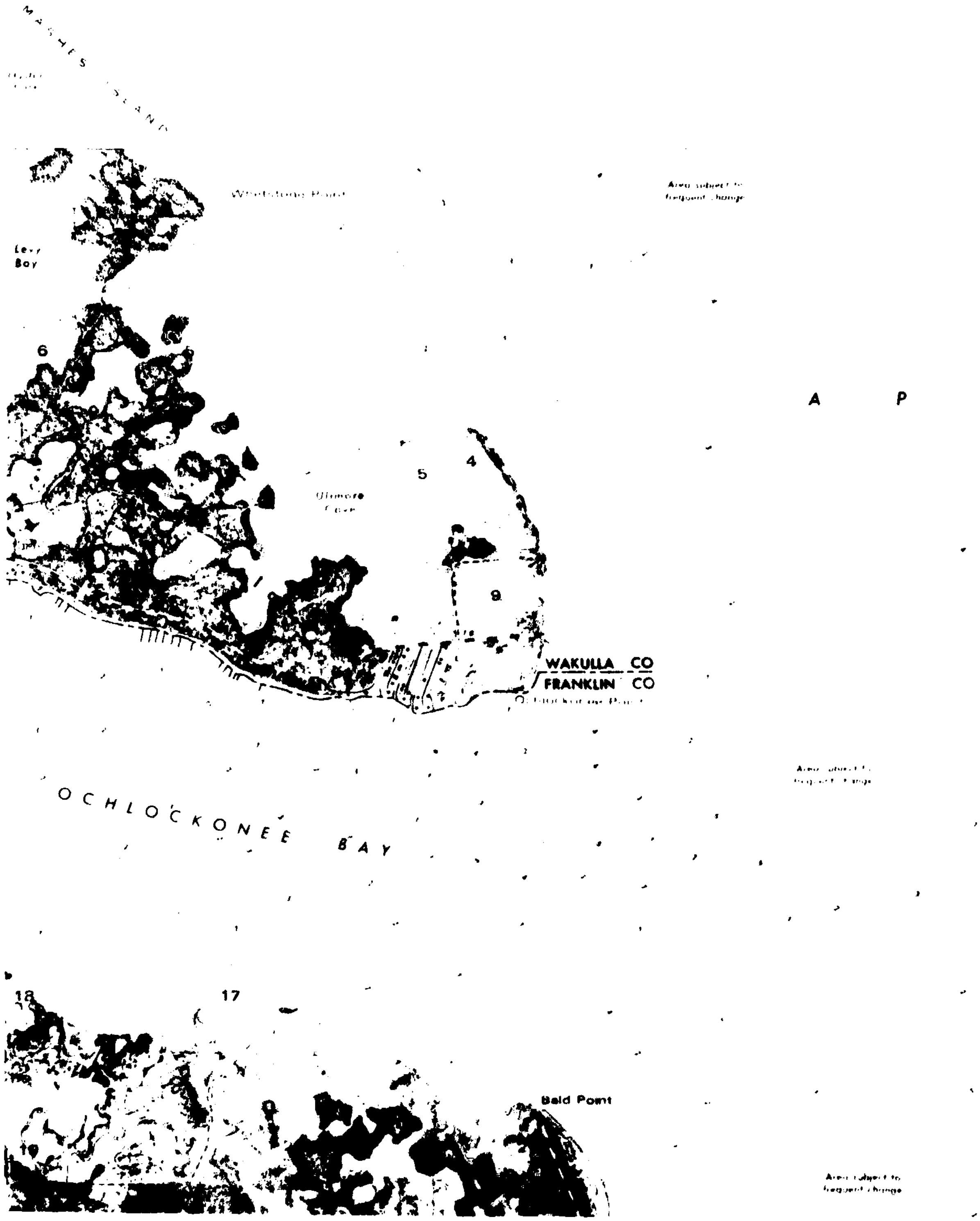


Figure A45. Segment 41

Figure A46. Segment 42

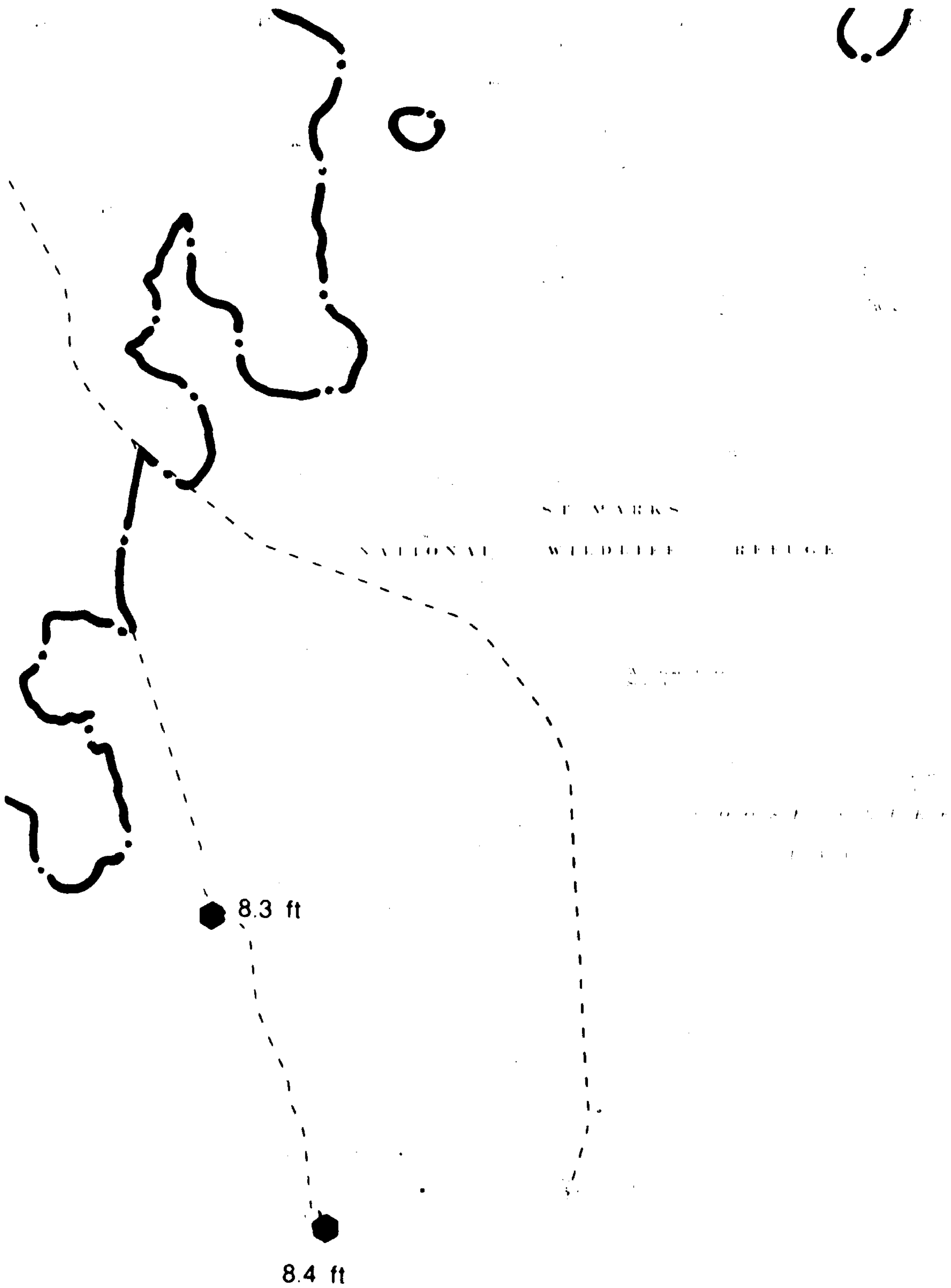


Figure A47. Segment 43

Figure A48. Segment 44

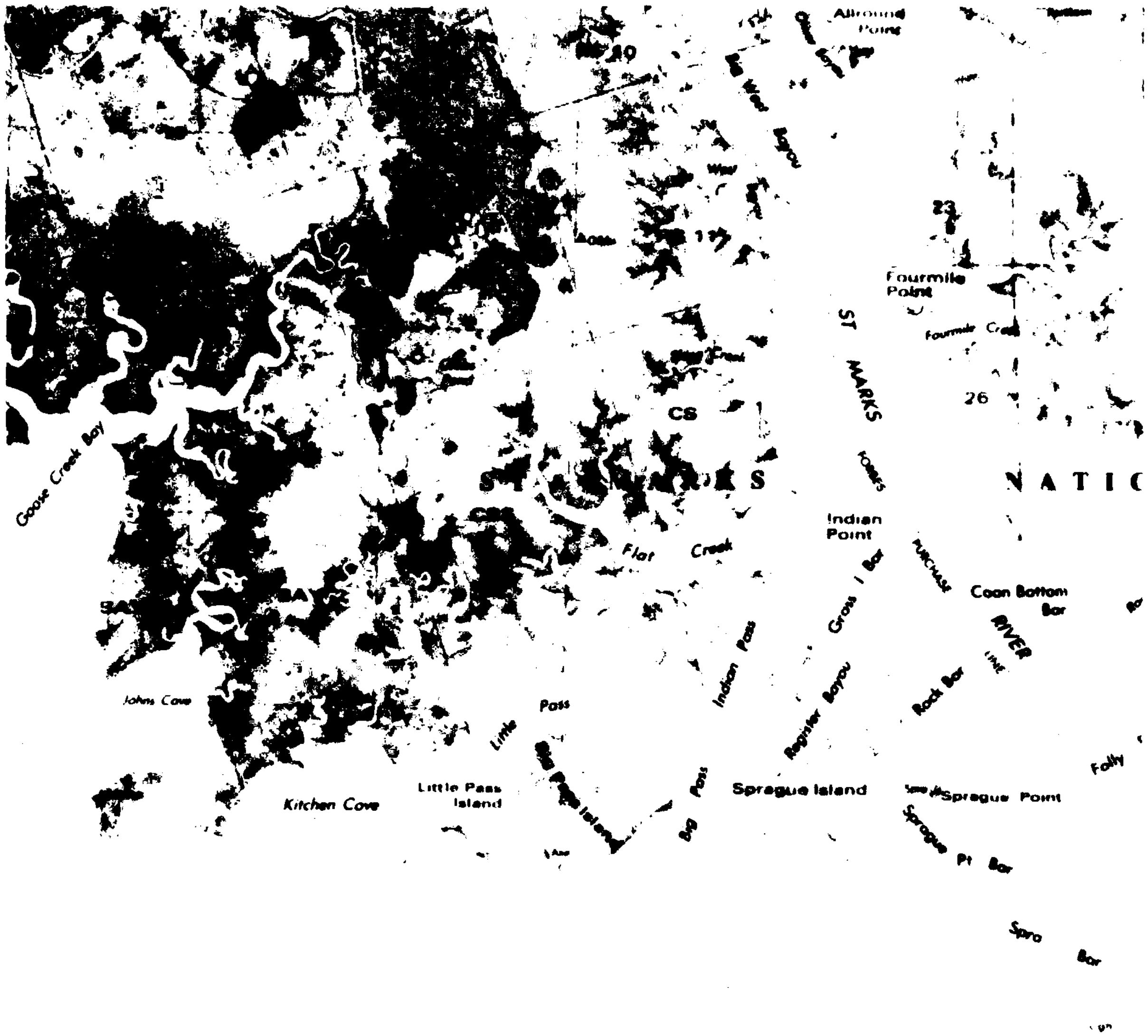


Figure A49. Segment 45

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